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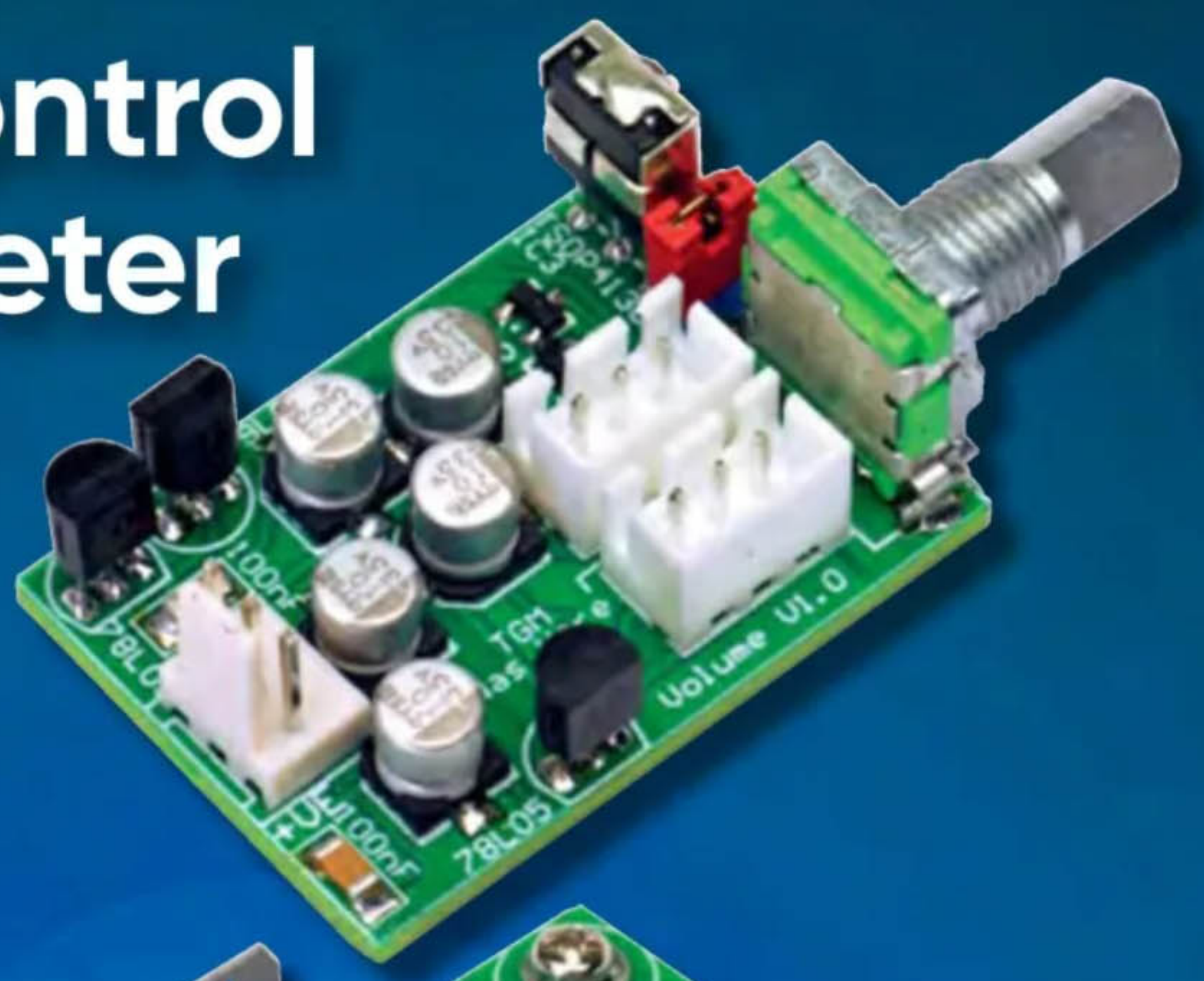
Audio Out
Designing discrete buffers

Building the Active Mains Soft Starter

Digital Volume Control Potentiometer



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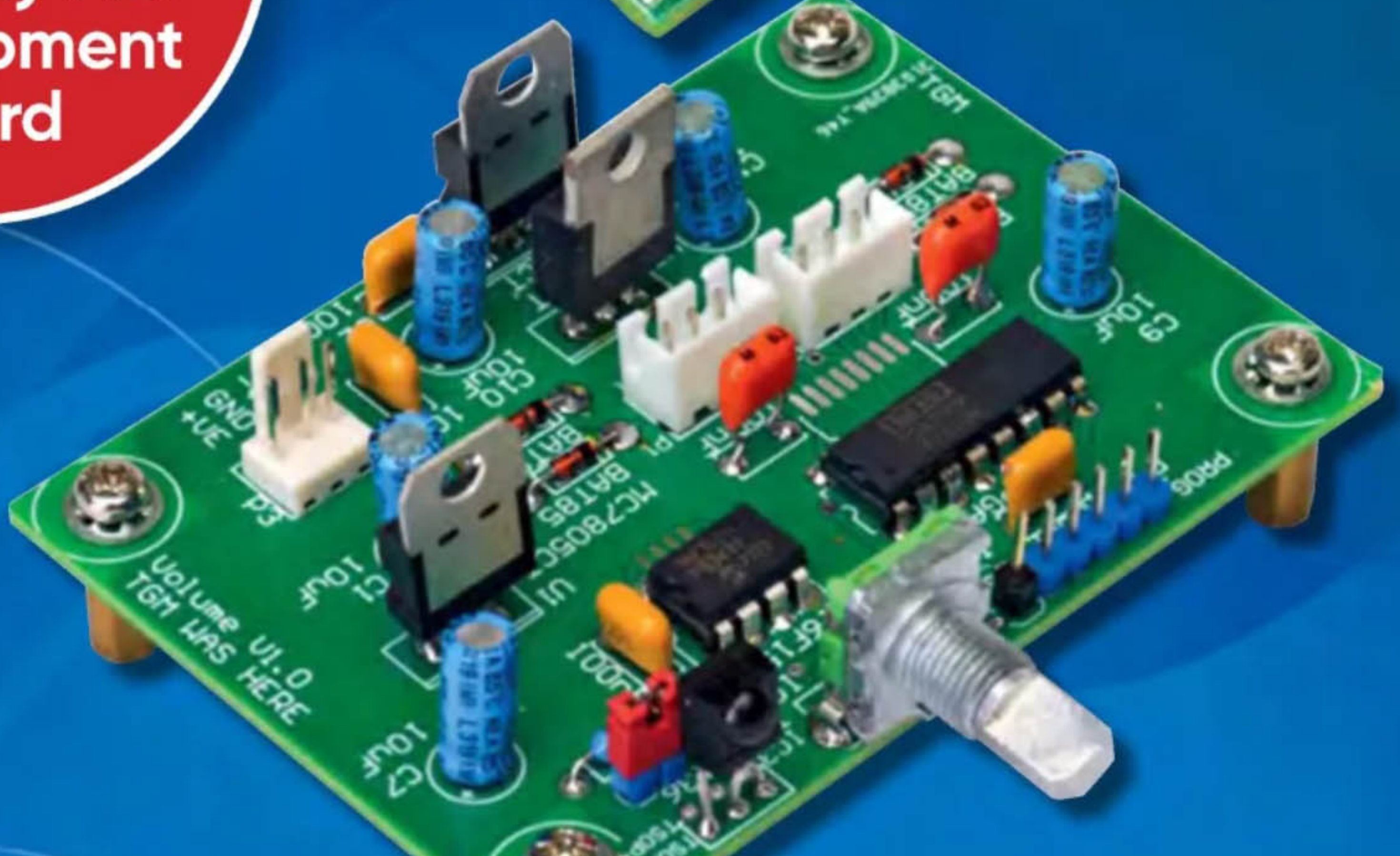
Microchip PIC32MK MCJ Curiosity Pro Development Board



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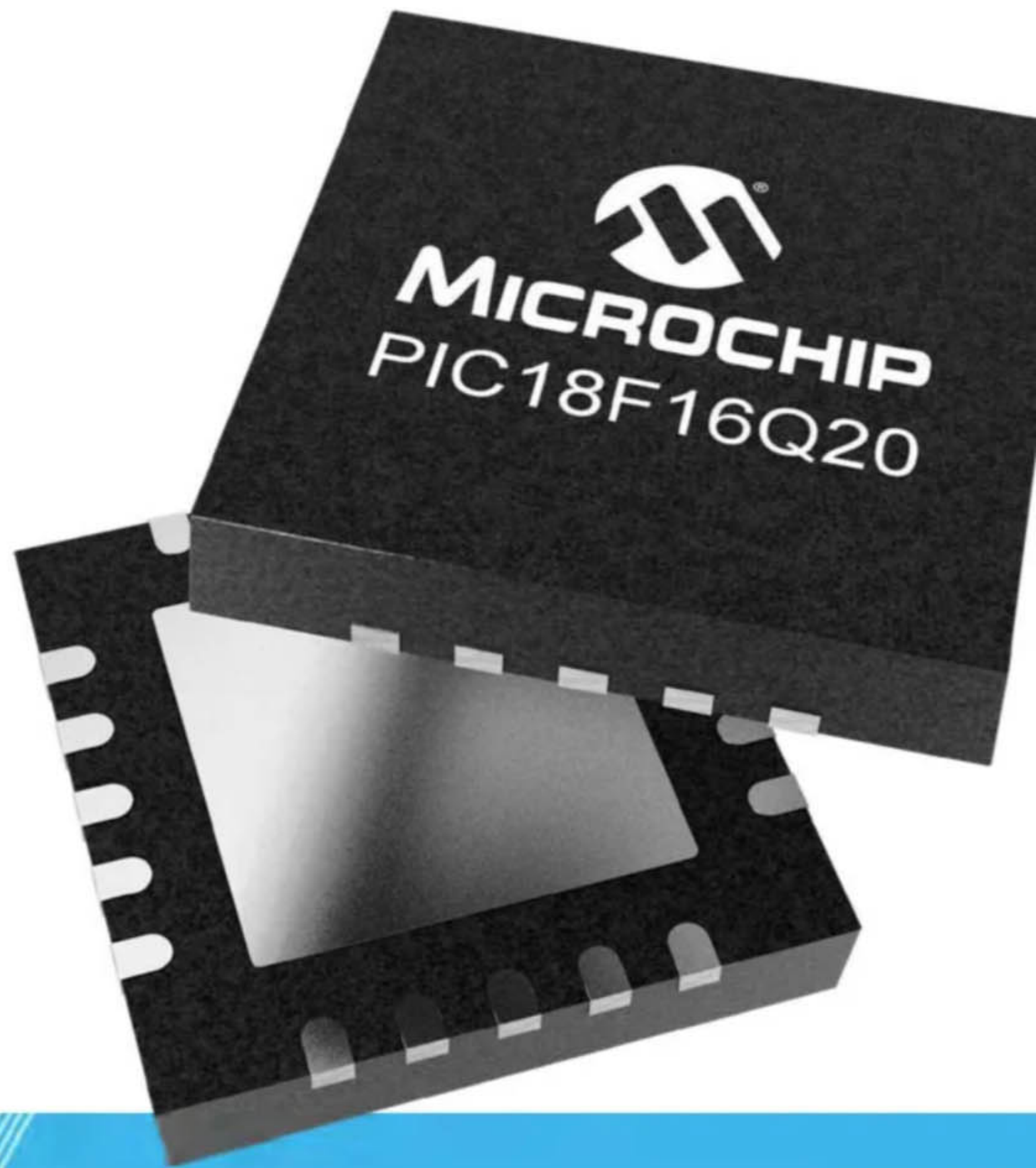

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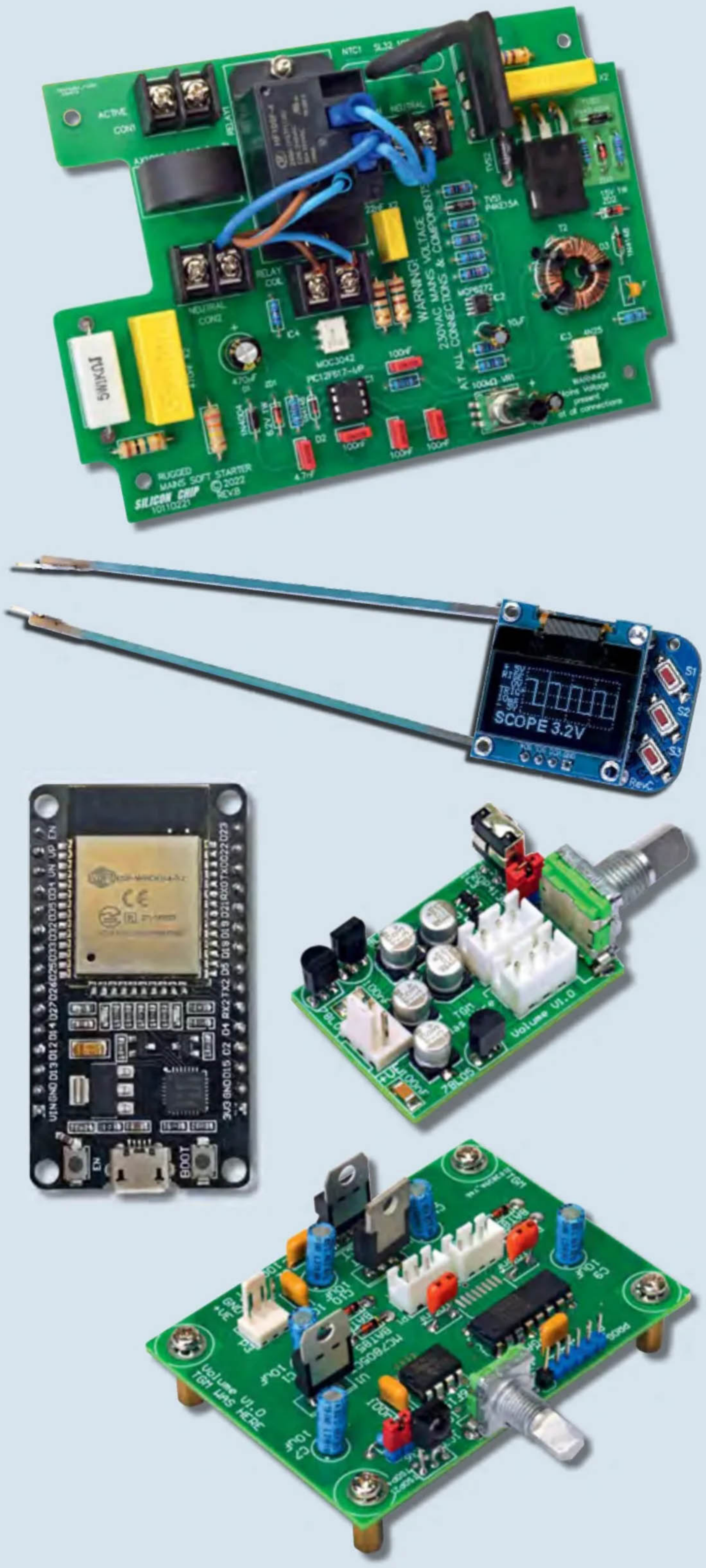

Projects and Circuits

Digital Volume Control Potentiometer by Phil Prosser 18
We got tired of volume control potentiometers going scratchy after just a few years, and very poor balance at low volumes. This drop-in replacement uses a digital IC, so it tracks exceptionally well and will give top performance for decades.

Advanced SMD Test Tweezers – Part 2 by Tim Blythman 28
This new design adds many features to the SMD Test Tweezers concept. No longer only for testing passive components, the new Tweezers can also act as a voltmeter, logic probe, basic oscilloscope, square wave generator and serial protocol analyser. This concluding article has all the construction and usage details.

Active Mains Soft Starter – Part 2 by John Clarke 36
Our Active Mains Soft Starter is ideal for eliminating the switch-on kick from power tools rated up to 750W. You can also use it to avoid high inrush currents for stationary equipment that can trip circuit breakers or wear out switches. This month, we cover the assembly, testing, adjustment and calibration of this new Soft Starter.

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The April 2024 issue of *Practical Electronics* will be published on Thursday, 1 March 2024 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

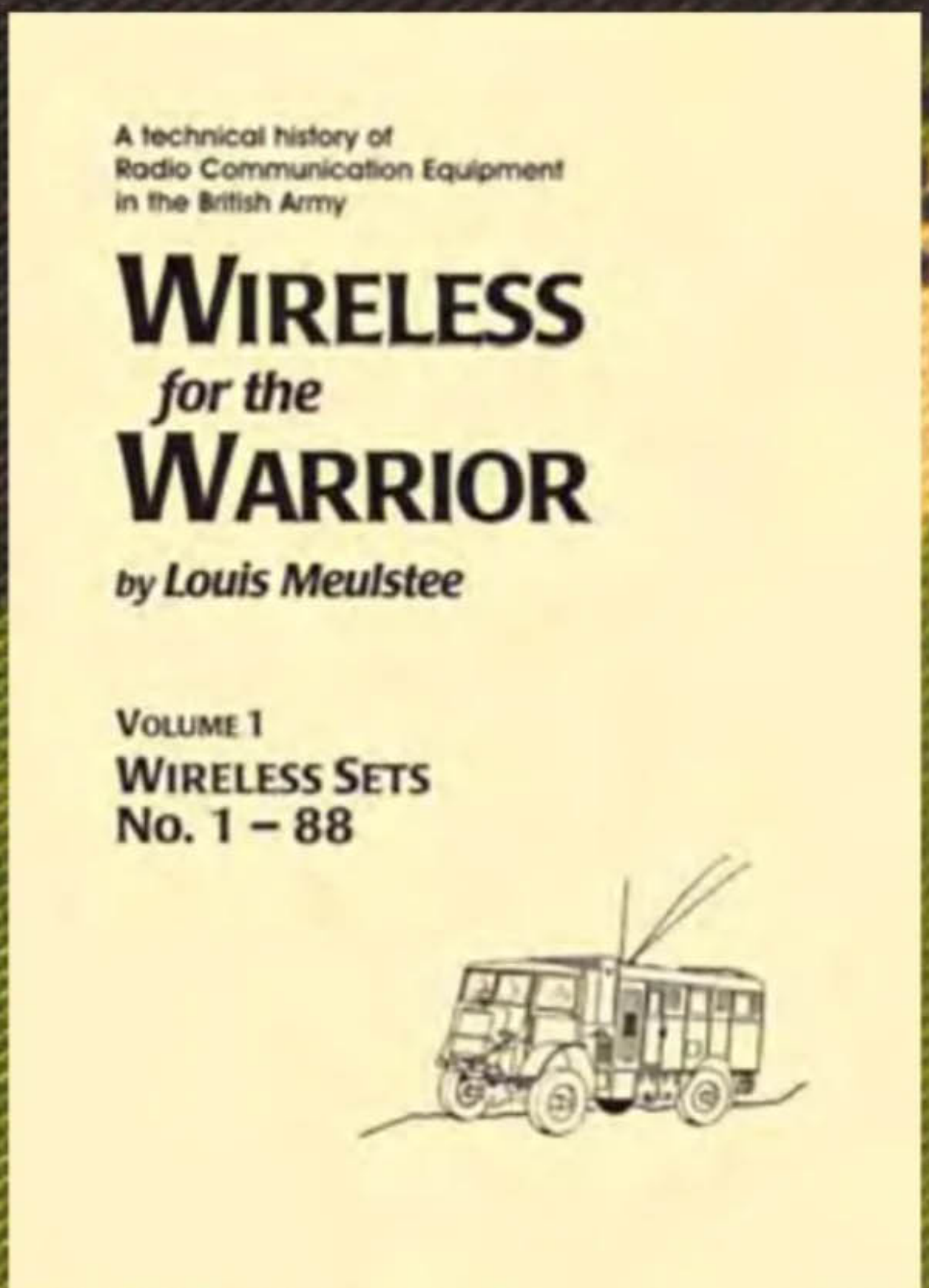
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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WIRELESS SETS
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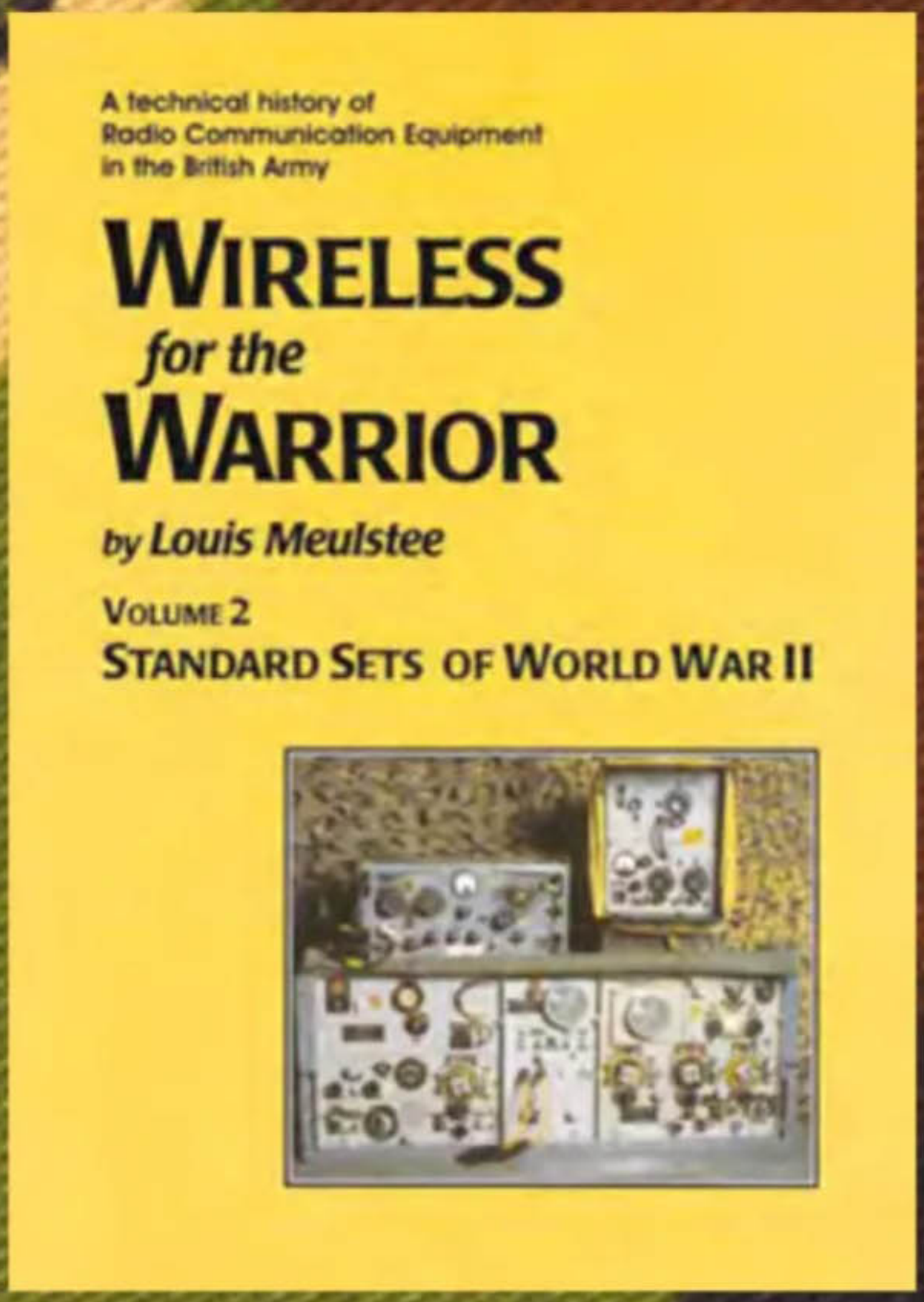

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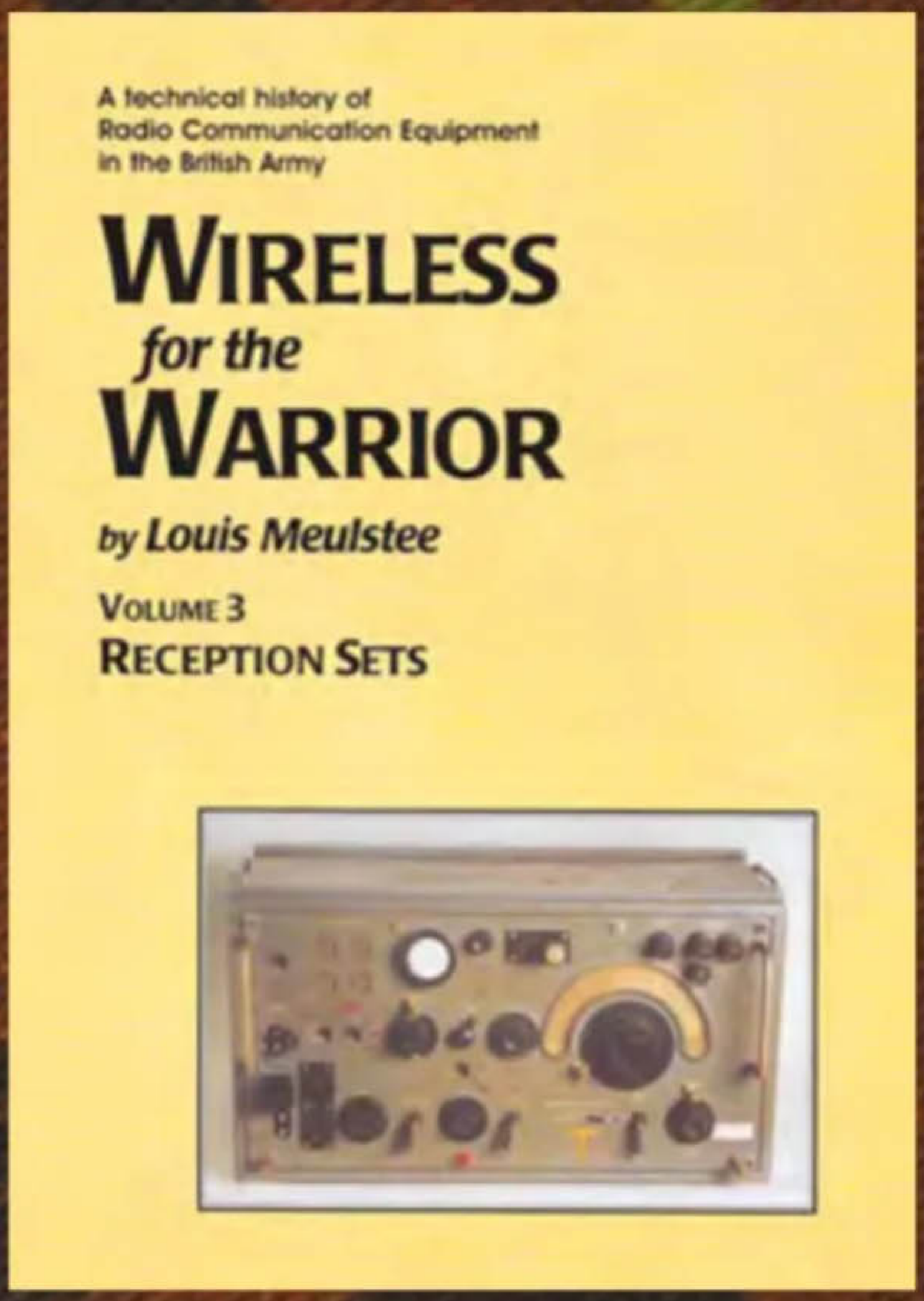

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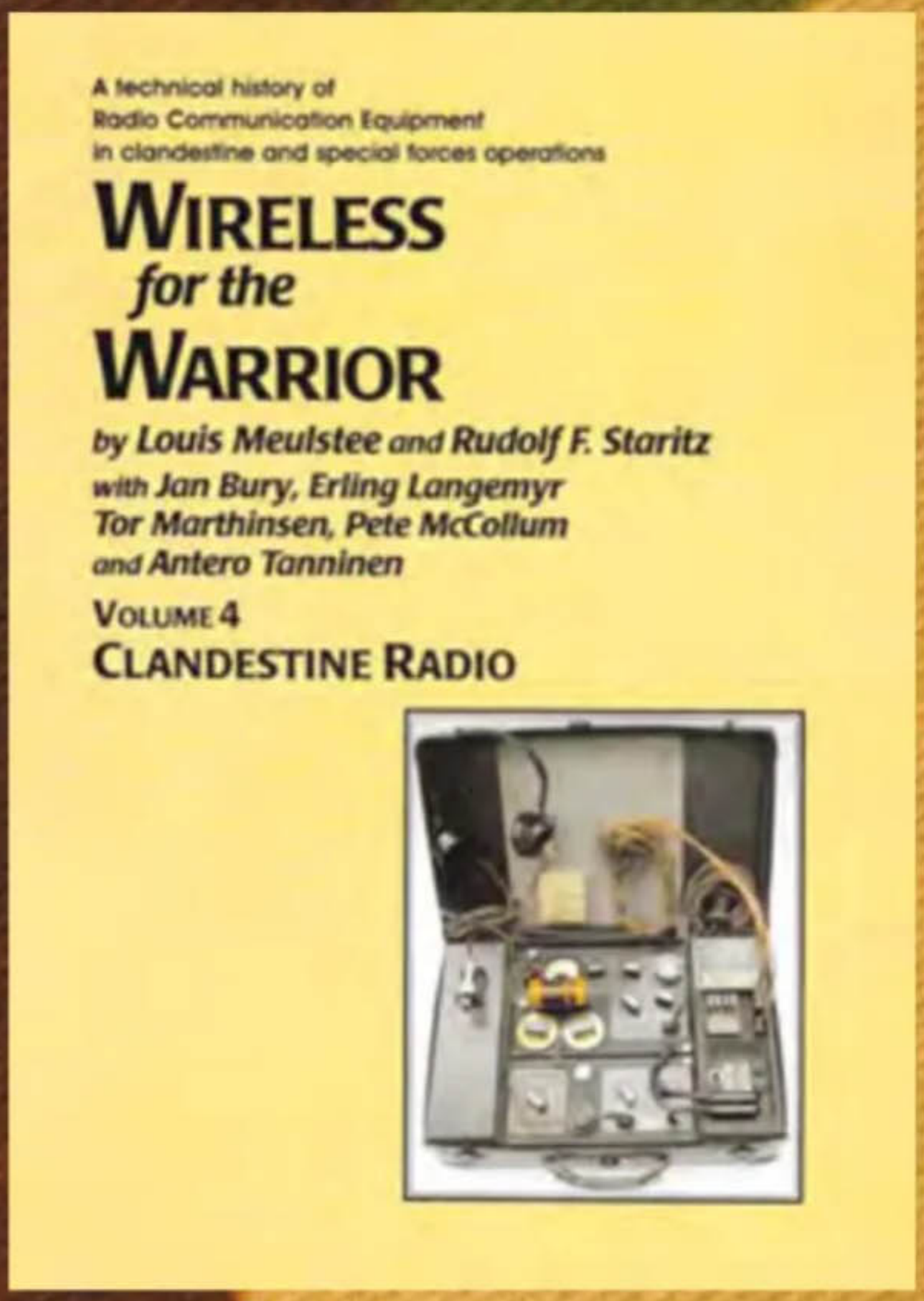

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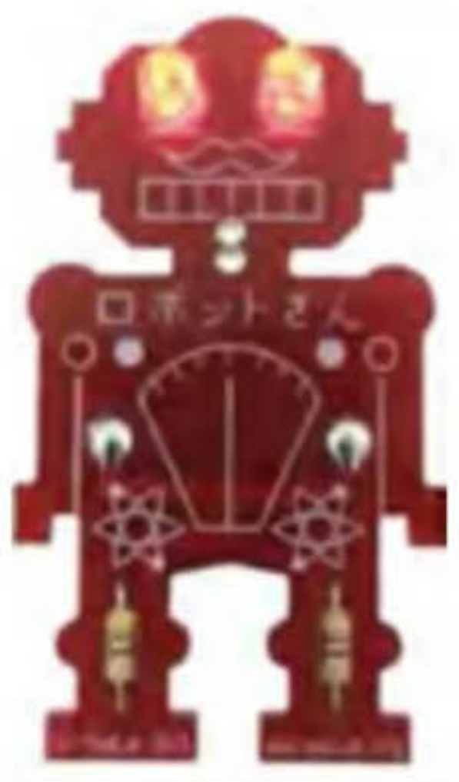
NEW! Mr Robot Kit



A fun, wearable electronic gadget that you can pin to your clothes. Easy to solder beginners kit. Two flashing bicolour LEDs resemble the eyes. 65 x 40 x 15 mm. CR2032 battery powered (not included).
Order Code: WSL108 - 6.68

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Still popular! A must-build soldering kit for all beginners. Dice slowly rolls to stop on a random number when the push button is released. 9V battery (not included). Ideal for educational courses. Wide selection of component types.
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3 outputs react to different sound frequencies. On-board microphone picks up surrounding sound or music and drives the low, mid & high frequency outputs. Connect 12-24Vdc RGB or separate colour LED strips or LEDs (not included). Master & separate channel sensitivity adjustment. 1.25 A max. per channel. Panel mountable facia 127 x 44mm. Terminal block or jack power supply connection. Control knobs included.
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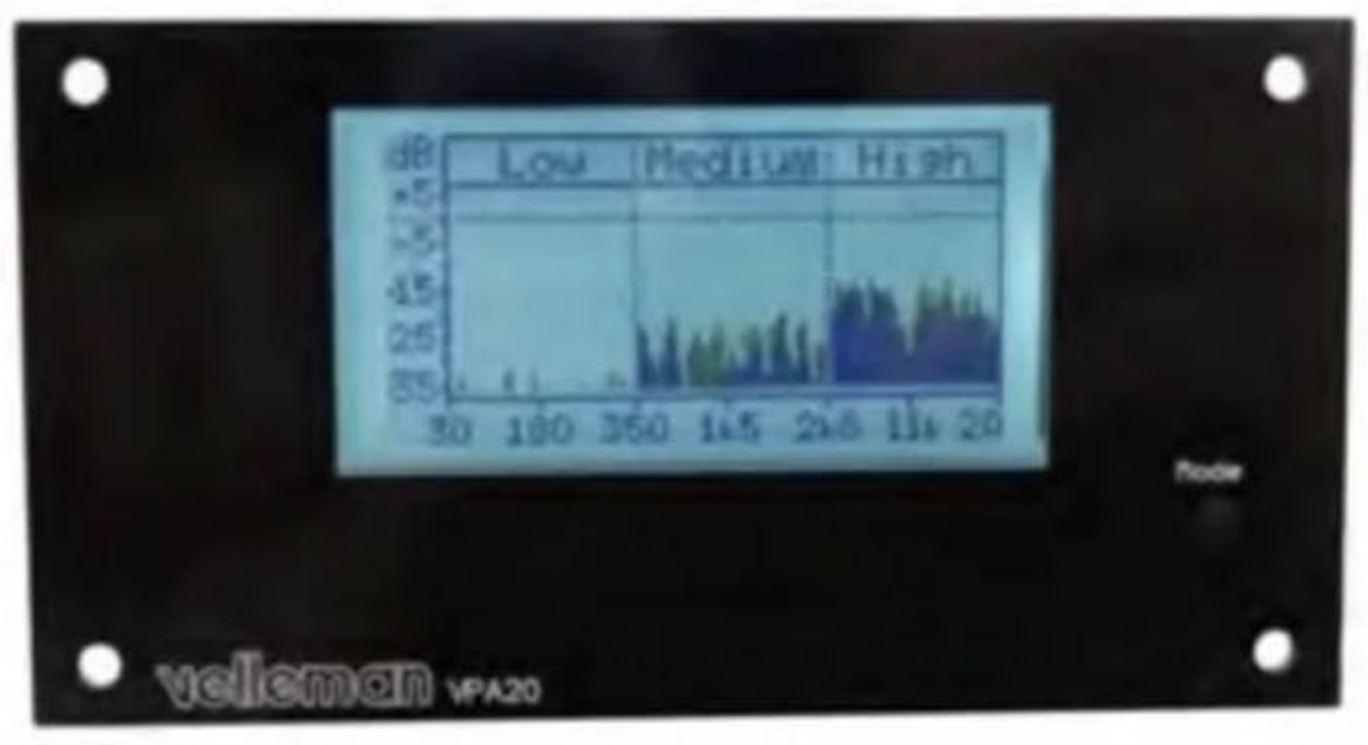

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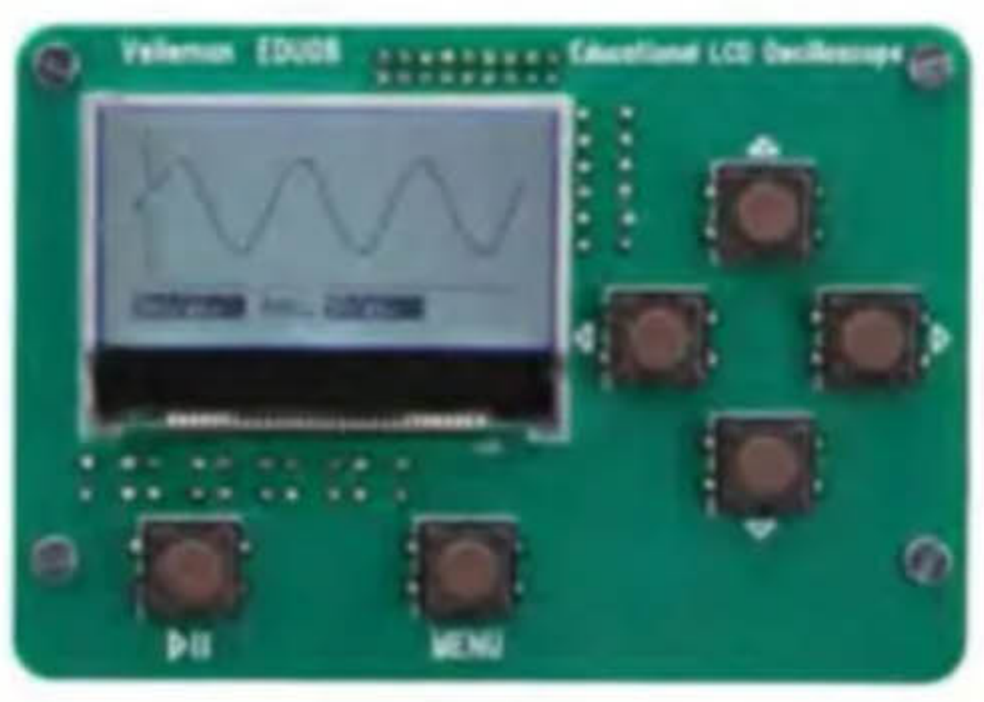

Build your own LCD oscilloscope with this exciting new kit. Learn how to read signals. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope kit has a lot of features found on expensive units like signal markers, frequency, dB, true RMS readouts and more. A powerful auto-setup function will get you going in a flash!
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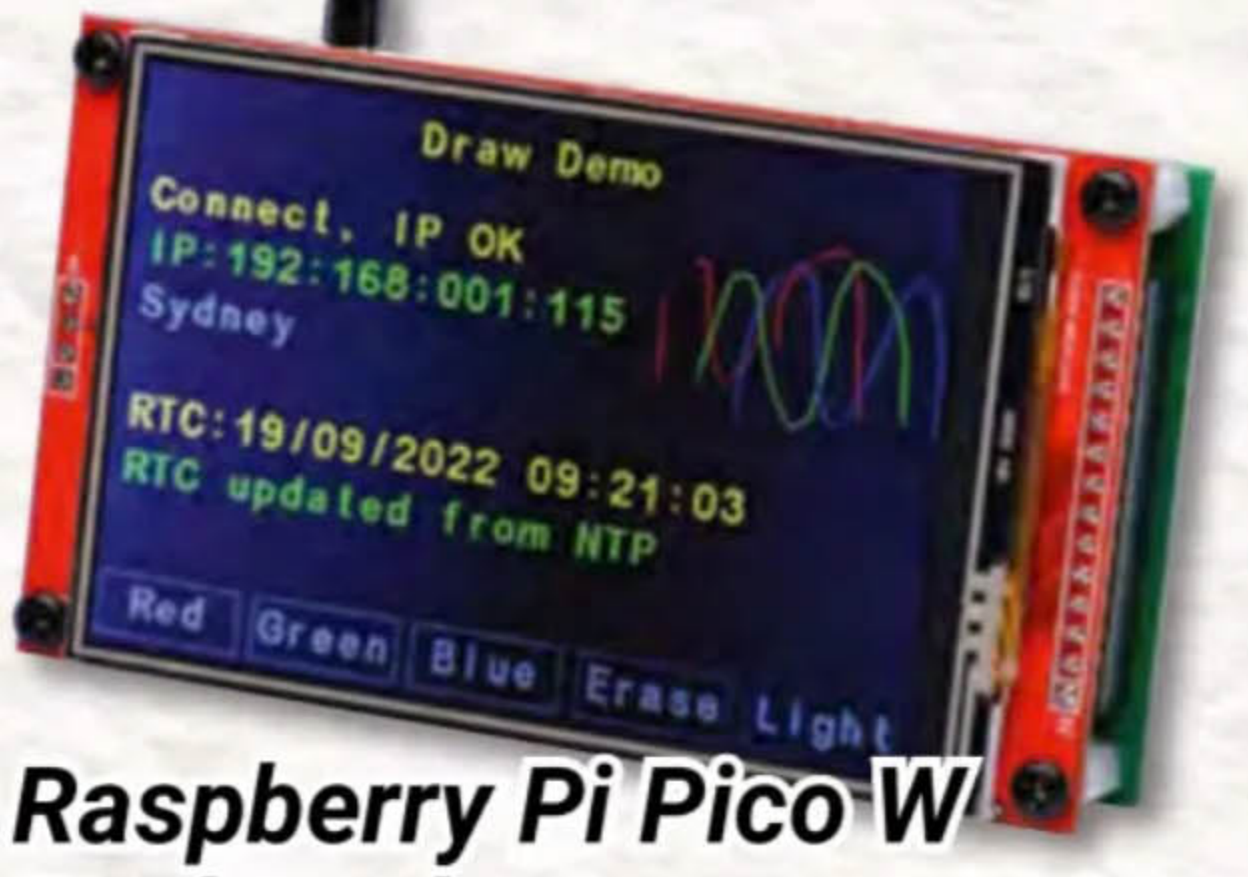
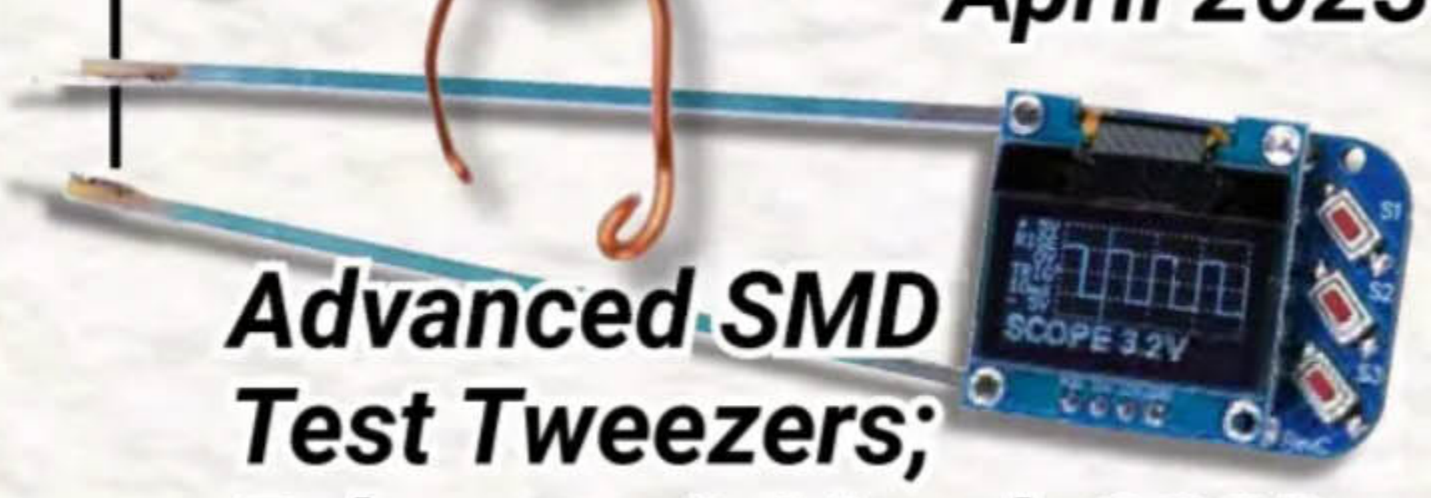

Draw Demo
Connect. IP OK
IP:192.168.001:115
Sydney
RTC:19/09/2022 09:21:03
RTC updated from NTP
Red Green Blue Erase Light

Raspberry Pi Pico W BackPack; January 2023

Wideband Fuel Mixture Display; April to June 2023

Silicon Chirp; April 2023



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Teach-In 2024

Well, last month we promised the return of *Teach-In* to *PE* and I'm delighted to say Mike Tooley has delivered. *Teach-In 2024* is based around the powerful inexpensive SoC (system on a chip) microcontroller the ESP32. I must confess that although I'd heard of the ESP32 I didn't really know that much about it – there are only so many microcontrollers one can keep up with! However, reading through *Part 1* I can see why Mike chose this device. It really does open up fascinating possibilities for projects, especially given its flexible connectivity, compact size and low power requirements. Lots to look forward to as the series rolls out over the year.

70s project still going strong

It's always nice to receive a bit of optimism during the cold, wet and windy month of January, and this week the following email from Mr Nigel Railton-Bennett landed in my inbox:

In 1971 I subscribed to your magazine and loved the contents: information, education and construction projects; many of which I made.

In this year, in particular, Shaw and Gibbs of Ferranti Ltd wrote up their design for the Practical Electronics Gemini Dual Purpose Stereo Amplifier. The specification was so good that there was nothing to beat it.

The purpose of this letter is to say that I built this amplifier, and then made any adjustments necessary outlined in future 'points arising' articles.

Since that time, this amplifier has been connected to everything that requires such a tool. I have a control box which can switch between various ancillaries, but everything goes through the amp: record turntable, open reel, cassette, CD, radio and TV. I have decent speakers of course.

The amplifier is only turned off if there is a power cut or when I move house, otherwise it is on day and night.

This is to commend Gibbs and Shaw and Practical Electronics for such a good job. Thank you.

And thank you Nigel – over 50 years and counting. That is truly an impressive run for a home-built project. Can anyone beat that? Any *PE* projects from the 1960s out there still up and running? I look forward to hearing about them.

Matt Pulzer
Publisher

The Wibbly-Wobbly World of Quantum

Techno Talk

Max the Magnificent

‘If someone says that he can think or talk about quantum physics without becoming dizzy, that shows only that he has not understood anything whatever about it.’
Murray Gell-Mann, American physicist

Things must have seemed somewhat straightforward (relatively speaking) towards the end of the 1600s. In the early part of that century, the German astronomer, mathematician, astrologer and natural philosopher Johannes Kepler published his three laws of planetary motion, accurately describing the orbits of planets around the Sun and showing them to have elliptical trajectories.

In 1666, the English mathematician, physicist, astronomer, alchemist, and theologian Sir Isaac Newton discovered his law of universal gravitation. Later, in 1687, he introduced his three laws of motion that describe the relationship between the motion of an object and the forces acting on it.

All of this led to the view that we live in a mechanistic universe, in which the natural world operates as a machine following predictable and deterministic rules. This has also been described as a ‘clockwork universe’ that keeps on ticking along. It’s tempting to think of a cosmic chronograph or a metaphorical metronome marking time such that it’s the same time at every point in the universe.

This ephemeral edifice came crashing down when Albert Einstein introduced his theories of special and general relativity early in the 20th century, showing how space and time are combined in a continuum. There are many implications to this, such as the fact that time passes at different rates depending on your velocity or proximity to massive obects... and then things start to get complicated.

What? You’re kidding!

Based on his experiments with optics, Newton decided that light was composed of some form of particles. However, some of Newton’s peers, such as Christiaan Huygens, took an opposing view that light was a kind of wave. Thomas Young’s original ‘double-slit’ interference experiments in 1801 indicated waves, but later versions served only to confuse the issue by indicating that light behaves as both waves and particles.

We now know that light manifests itself in what we call photons, which are massless particles, or electromagnetic waves, depending on your point of view.

The idea behind the double-slit experiment is to have an opaque plate pierced by two parallel slits. Photons passing through the slits are detected by some form of sensor behind the plate.

Let’s assume that we use some sort of ‘photon gun’ to fire a series of individual photons at the plate, one after the other. If we use one form of detector, it appears that each photon passes through one slit or the other (or hits the opaque portion of the plate) like a miniature cannon ball, thereby indicating that photons are particles. But if we use a different sort of detector, we see interference patterns. This implies that each photon acts as a wave, passing through both slits simultaneously and interfering with itself on the other side.

Initially, scientists were tempted to treat photons as a special case and say something like, ‘Photons, what can you do, eh?’ However, it was later discovered that the same thing happens with electrons, protons, atoms and even molecules (the largest entities for which the double-slit experiment has been performed thus far are molecules comprising 2,000 atoms).

It gets worse. The term ‘quantum entanglement’ refers to the ability for two particles to be linked (‘entangled’) such that a change in one will affect the other, even if they are separated by distances measured in light years. Furthermore, these changes will take place instantaneously, even though physicists continue to claim that nothing, including information, can travel faster than light. Suffice it to say that Albert Einstein referred to quantum entanglement as ‘Spooky action at a distance’ and then quickly changed the topic of conversation.

Quantum computers

For a long time, protons and neutrons were assumed to be fundamental and indivisible particles. Later it was discovered that they are formed from more elementary particles called quarks, which have been described as, ‘The dreams that stuff is made of.’

Im the 1980s, Richard Feynman and Yuri Manin proposed using quantum effects as the basis for quantum computers. In the digital computers we use today, the fundamental unit of information is the bit, which can be in one of two states: 0 or 1. The equivalent in a quantum computer is the ‘qubit’, which involves something like the spin of an individual electron. We might think of this ‘up’ or ‘down’ spin as being the equivalent of 0 and 1, respectively. However, a qubit exists in a coherent superposition of both states simultaneously, which basically means it represents all possible values between, and including, the extremes at once.

The first real quantum computer that could be loaded with real data and output a real solution was a 2-qubit machine created in 1998. The largest quantum computer of which I’m currently aware is the 1,180-qubit machine that was announced by *Atom Computing* in October 2023.

There are some problems that are hard for traditional digital computers to solve using conventional ‘grunt force’ means. One example is a complex maze, which you or I (or a digital computer) would solve by testing each possible path one after the other, retracing our steps when we ran into a dead end. Some people describe a quantum computer’s approach to this problem as looking at all the paths simultaneously. This isn’t quite how it works, but thinking about it in this way helps to preserve our quantum-world sanity.

In the real world, it will soon be possible to present a quantum computer with problems that would take a digital computer millions of years to solve, and for the quantum machine to solve those problems in seconds. When will this come to pass? All I can say is that the future is closer than we think.

Where’s the ripe fruit?

As Terry Pratchett famously noted in the *Night Watch* tome of his *Discworld* series: ‘It’s very hard to talk quantum using a language originally designed to tell other monkeys where the ripe fruit is.’ It doesn’t matter if you are a devotee of bits or a disciple of qubits, it’s hard to argue with logic like that!

Win a Microchip PIC32MK MCJ Curiosity Pro Development Board

Practical Electronics is offering its readers the chance to win a Microchip PIC32MK MCJ Curiosity Pro Development Board (DT100113) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

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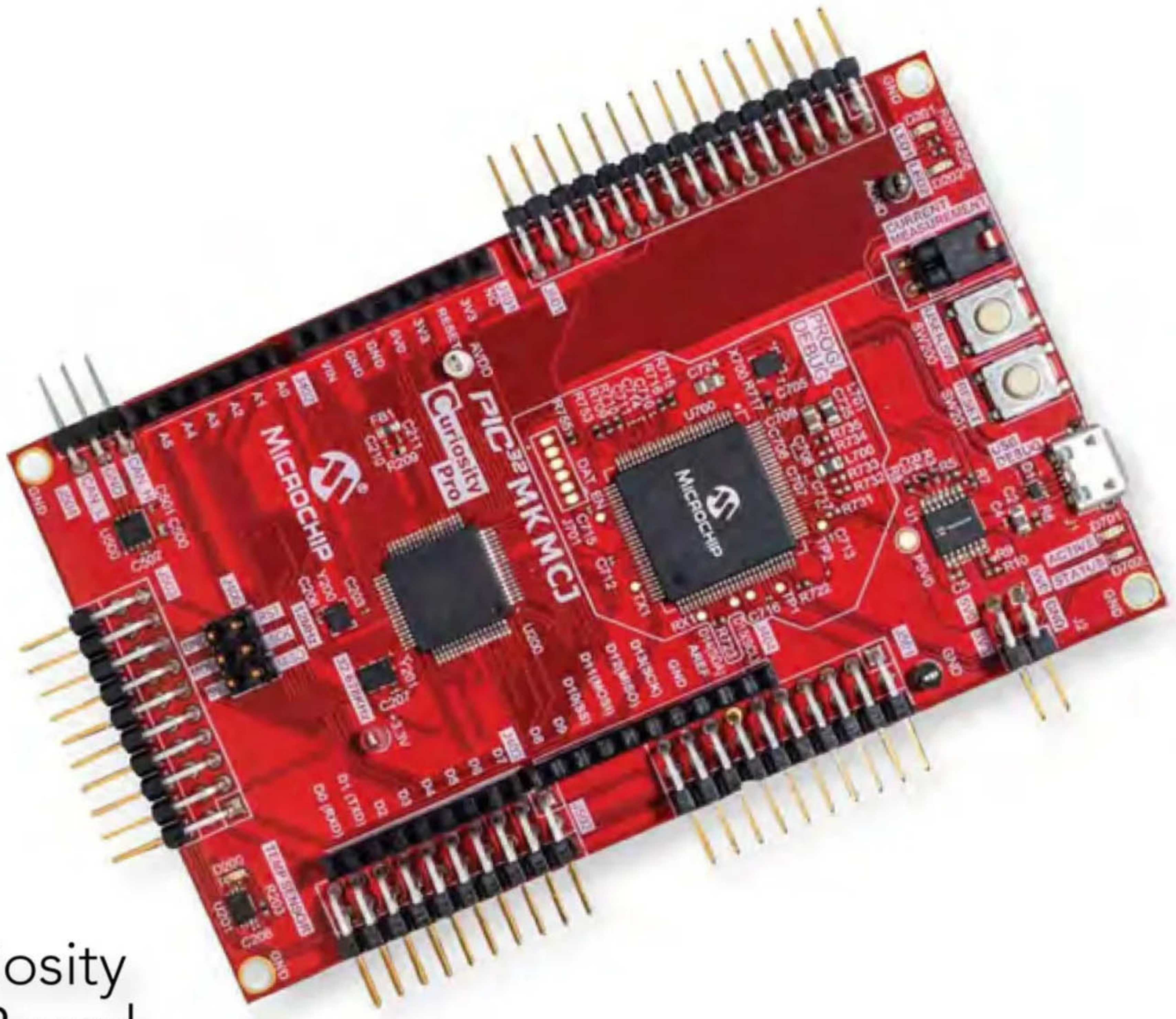

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The closing date for this offer is 28 February 2024

November 2023 winner

Jamie Cunningham

Jamie won a Microchip MPLAB PICkit 5

Net Work

Alan Winstanley

This month's Internet and tech column explains how the role of cookies is changing and the headaches they are giving the publishing sector. There's an update on the rollout of Windows Copilot, a roundup of the latest moonshot news, and Alan gets a surprise spin in a Honda e:Ny1 BEV.

Some 40 or 50 years ago, the pages of *Practical Electronics* and *Everyday Electronics* were crammed with adverts for mail-order suppliers, and a few towns and cities often had a component or surplus shop tucked away that offered an invaluable postal service for hobbyists. In those heady days trade was brisk, and occasionally so many suppliers were jostling to advertise in our pages that some of them had to be turned away.

Fortunately, component shops still exist and ESR Electronic Components (**www.esr.co.uk**), JPG Electronics near Sheffield (**www.jpgelectronics.com**) and London-based Cricklewood Electronics (**www.cricklewoodelectronics.com**), to name three, continue to offer a bricks-and-mortar store along with online ordering, backed up by traditional levels of personal customer service. Having a choice is a good thing, and hard-working independent stores like these deserve continued support.

Not every business felt the need to embrace the Internet, though, and I recall visiting the renowned J Birkett electronic component shop at the bottom of Steep Hill in Lincoln, a shop that was once a regular advertiser (for magazine collectors, see the March 1981 issue of *Everyday Electronics*). I occasionally called in at Birkett's and I usually ended up buying lots more than I'd intended to. The late John Birkett was well-known in radio ham circles: it seems he eschewed the idea of a website altogether and was content with word of mouth, which is often the best salesman. One radio enthusiast pays tribute at: **https://bit.ly/pe-mar24-jb** and you can stroll by the store on Google Street View at: **https://bit.ly/pe-mar24-jb2**

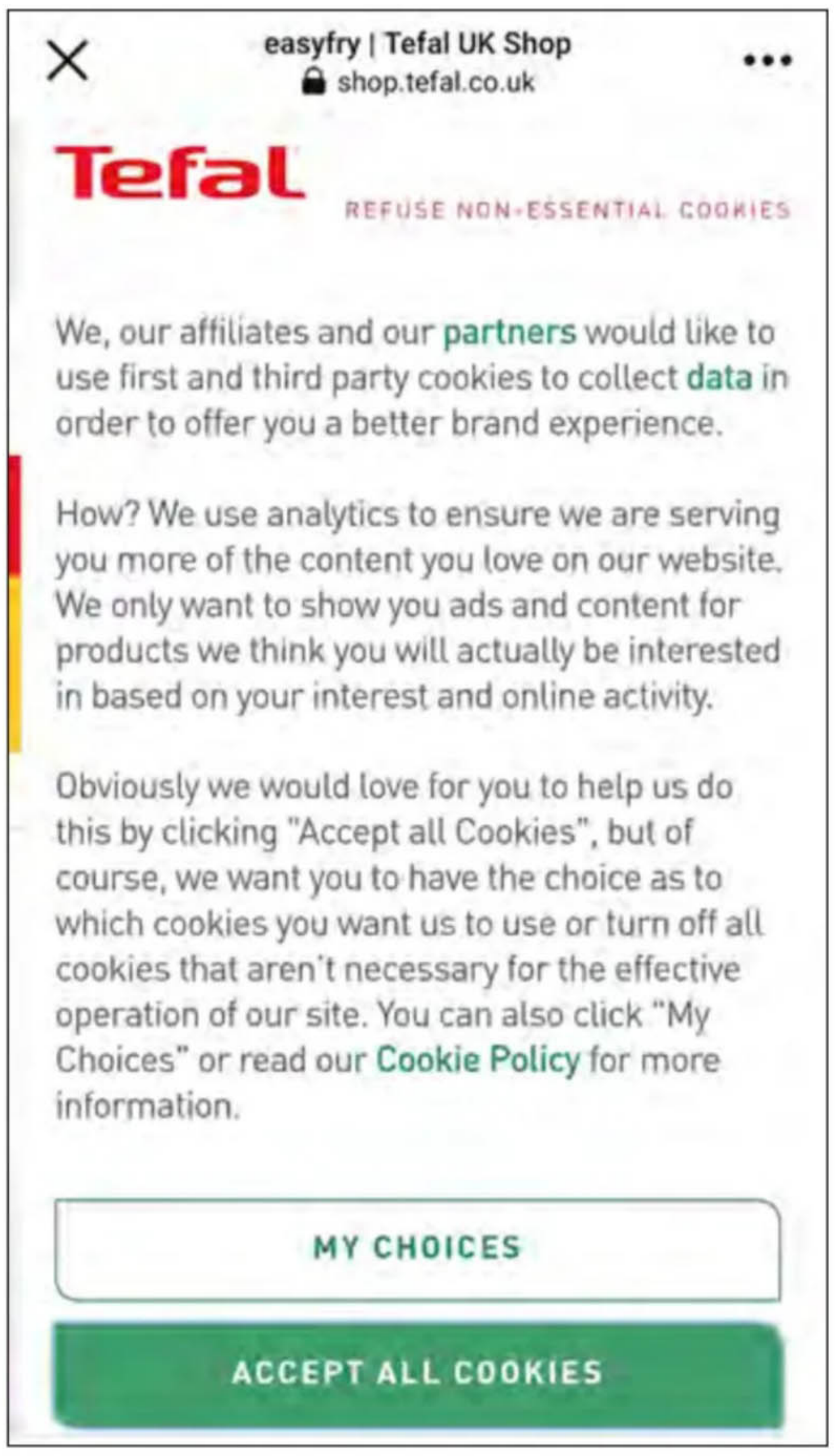
Another website I use for buying spares has only half-heartedly adopted the web; the proprietor simply scribbles online orders out onto a delivery note, unconcerned about introducing mistakes along the way. Well, it works for him, I suppose!

Crumbling cookies

One of the essential moving parts of the world-wide web is the *cookie* – benign-looking text files that many websites place onto a visitor's computer system in an effort to identify it. They can contain obscure data that tracks your online history, or they may help to authenticate your identity before proceeding with, say, an online banking session. Sometimes cookies are needed to enable a website to operate correctly and, helpfully, cookies can enable E-commerce sites to restore the contents of your shopping cart in case you accidentally close a website during some busy browsing. If a site isn't behaving as expected, another tip is to check whether pop-ups have been disabled. Thanks to cookies, a device can remain 'logged in' to websites after you finish – that's a good reason to ensure you log out properly, especially if using a computer terminal in a public library, for example.

Cookies are also behind the web's creepy ability to track your movements and target you with advertisements. It comes as no surprise, these days, when you visit a website looking for car insurance or clothing, only to face a torrent of annoying adverts for the same kind of thing when you browse, say, a newspaper website afterwards. The web industry says that drumming up trade based on targeted advertising this way helps to keep the rest of the web 'free'.

The use of cookies has given rise to a multitude of data protection regulations in recent years, resulting in website visitors needing to consciously 'opt in' to accept them. Some websites show a laundry-list of cookie options that you must either accept or reject before proceeding any further, but I suspect that those tiresome pop-ups are just dismissed without a second thought, thereby snaring the visitor into accepting more online marketing and spam email.



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Some websites may not function properly, if at all, unless visitors opt in to accept cookies. This example is from the Tefal UK Shop website.

Privacy, sandboxed

The good news is that some of these marketing techniques are falling out of fashion. So-called 'third-party cookies' – ones connected to a website *other than the one you visit* (which is the 'first-party') – litter the web and 'cross-site trackers' enable third parties to follow you around the web and subsequently target you with relevant advertising. That's why your device screen may fill up with online adverts influenced by your web surfing history. Other cunning techniques used by some web marketers include checking a combination of your device's software and hardware to produce a unique hash or 'digital fingerprint' which, unlike ordinary cookies, can occur without a user's consent. Fortunately, these unethical techniques seem to be quite rare. You can test and compare your system's fingerprint from nearly 60 attributes using the website: **https://amiunique.org/fingerprint**

Currently under development, the Privacy Sandbox is a Google initiative designed for Google's Chrome web browser and Android that aims to make third-party cookies redundant in favour of more advanced techniques that will 'reveal [a website user's] patterns of behaviour', as they unashamedly admit. This drive for 'better privacy' has been in the works for several years, and it hopes to 'create technologies that both protect people's privacy online and give companies and developers tools to build thriving digital businesses', they say. 'The Privacy Sandbox [initiative] reduces cross-site and cross-app tracking while helping to keep online content and services free for all', according to the campaign website: **https://privacysandbox.com**

'People should be able to enjoy their browsing and app experience without worrying about what personal information is collected, and by whom,' they solemnly declare, as if anyone would disagree. '… The Privacy Sandbox technologies aim to make current tracking mechanisms obsolete, and block covert tracking techniques, like fingerprinting.'

Google is far from alone in doing this, though: Apple's iPhone App Tracking Transparency defeats web tracking and it cost Facebook an estimated $12bn in lost ad revenue, according to Forbes back in 2022. Apple's Safari browser also has tracking prevention. Microsoft Edge lets users choose the level of privacy protection in Settings / Cookies and Site Permissions (where I noticed my Edge browser allows third-party cookies by default). Mozilla Firefox users can click the shield icon in the address bar to access its Protection Dashboard settings, and the Opera web browser offers similar options.

Remember that legitimate third-party cookies may still be needed to make a complex shopping cart or website work properly, if at all, so be prepared to allow exceptions anyway. Google's proposals include a temporary opt-in to allow essential third-party cookies to run if needed. According to a Google developer blog, Google has already started down the road of disabling third-party cookies, with 1% of Chrome users worldwide being chosen at random to test their new Tracking Protection, and Google says that all third-party cookies will be disabled [in Chrome] by the end of this year.

Online marketers are gearing up for a dystopian world in which third-party advertising cookies have been axed and web visitor click-throughs have dried up. Looking ahead, the trend will be towards exploiting 'first-party' website visitor data instead. The major difference is that a first-party cookie can still be delivered onto your device, but it will only be downloaded from the website *that you're actually visiting*, meaning no cookies from third parties will be lurking around. Any interaction takes place strictly between you and the first-party website. The hope is that this will preserve user privacy, but it also makes website visitor data (analytics) more meaningful for the website owner.

Bad news days

Over in the news media sector, the move to deprecate third-party cookies, and therefore kill off the news publishers' online advertising, has added to the woes of a global publishing industry that is already in turmoil. News publishers are being squeezed by the knock-on effects of inflation, and advertising revenue is already in free-fall with demand for goods and services falling because of consumer uncertainty. Their online news feeds are often free only because they are funded by advertising, so some news outlets (eg the *Daily Mail*) are said to be considering implementing a paywall to raise some revenue. It's likely that many media sectors will be introducing subscriptions or membership plans to make up for falling sales.

Another consequence is the damage caused to local news journalism. One British and Irish media publisher, Reach, the group behind the *Daily Express*, *Mirror* newspaper and more, is also well known for its regional 'Live' news sites. It was recently forced to closed 13 of them altogether, including *Hampshire Live* and *Norfolk Live*, as it strives to reduce overheads by 6%.

Another front is also opening in the war between news publishers and the Internet media giants, as chatbots might conceivably be used as 'journalists', their 'generative' AI answering queries or writing pieces on news events based on content scraped from news media sites. After being 'trained' for several years purely on archived media during their development phase, AI bots may now be unleashed onto *live* news sites, which could see Bing (GPT) or Google (Bard), for example, crawling and citing news content related to current events – copyrighted content that is written by real journalists and belongs to the news publisher.

News media sites are set to retaliate by blocking AI bots from crawling their content, while trying to ensure that they are not blocked from search engine results at the same time. With online marketing techniques evolving rapidly in the name of safeguarding user privacy, the entire news media landscape is set to change as journalism and Internet giants lock horns with each other.

Copilot, take control

I mentioned in the August 2023 issue that Microsoft was busily replacing Cortana, its largely unloved voice assistant, with Copilot, an altogether more user-friendly AI-powered chatbot that is set to change the way users and Microsoft Windows interact with each other. Copilot has now been implemented in the Microsoft Edge web browser – in Edge, a keystroke combination of CTRL + SHIFT + . (full stop/period) opens up or toggles Copilot with Bing, where you can type in human-recognisable search expressions and Bing will respond with an uncanny chat style. You can also use the tab key to follow Bing's search term autocomplete suggestions. A microphone icon has also appeared, allowing users to talk directly, which saves the need to type in search terms. On a desktop PC, a webcam's microphone can handle this, and Bing's voice recognition is pretty impressive. Bing can also read out the chat 'conversation'.

According to the Tech Radar website, Copilot 2.0 is slated for appearance in a Windows 11 update later this year, leaked documents suggest. Significantly, the Copilot chatbot may simplify user Help routines and Windows computer

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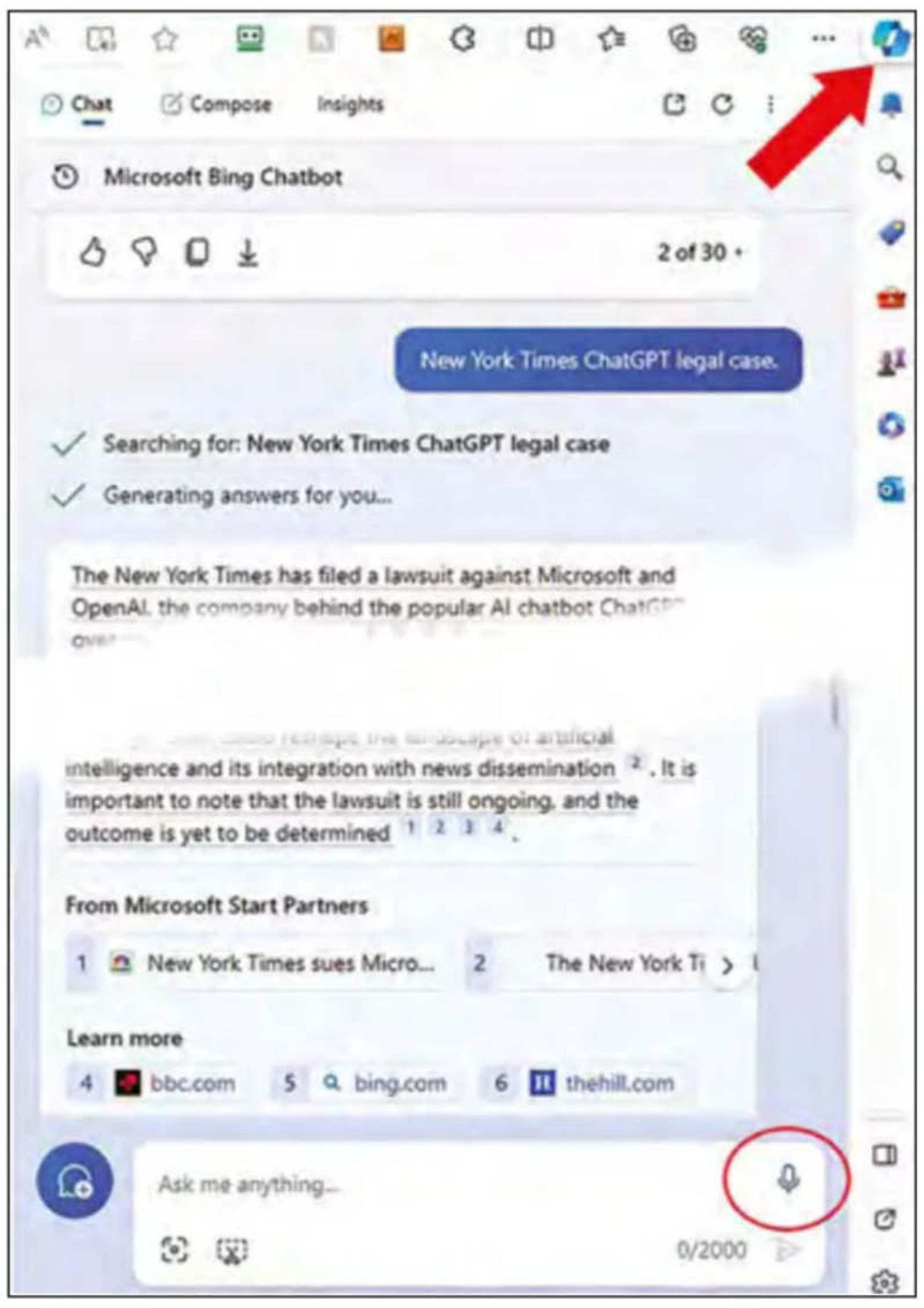
Chat
Compose
Insights
Microsoft Bing Chatbot
2 of 30
Ask me anything...
0/2000

New York Times ChatGPT legal case.

Searching for: New York Times ChatGPT legal case

Generating answers for you...

The New York Times has filed a lawsuit against Microsoft and OpenAI, the company behind the popular AI chatbot ChatGPT

intelligence and its integration with news dissemination 2. It is important to note that the lawsuit is still ongoing, and the outcome is yet to be determined 1 2 3 4.

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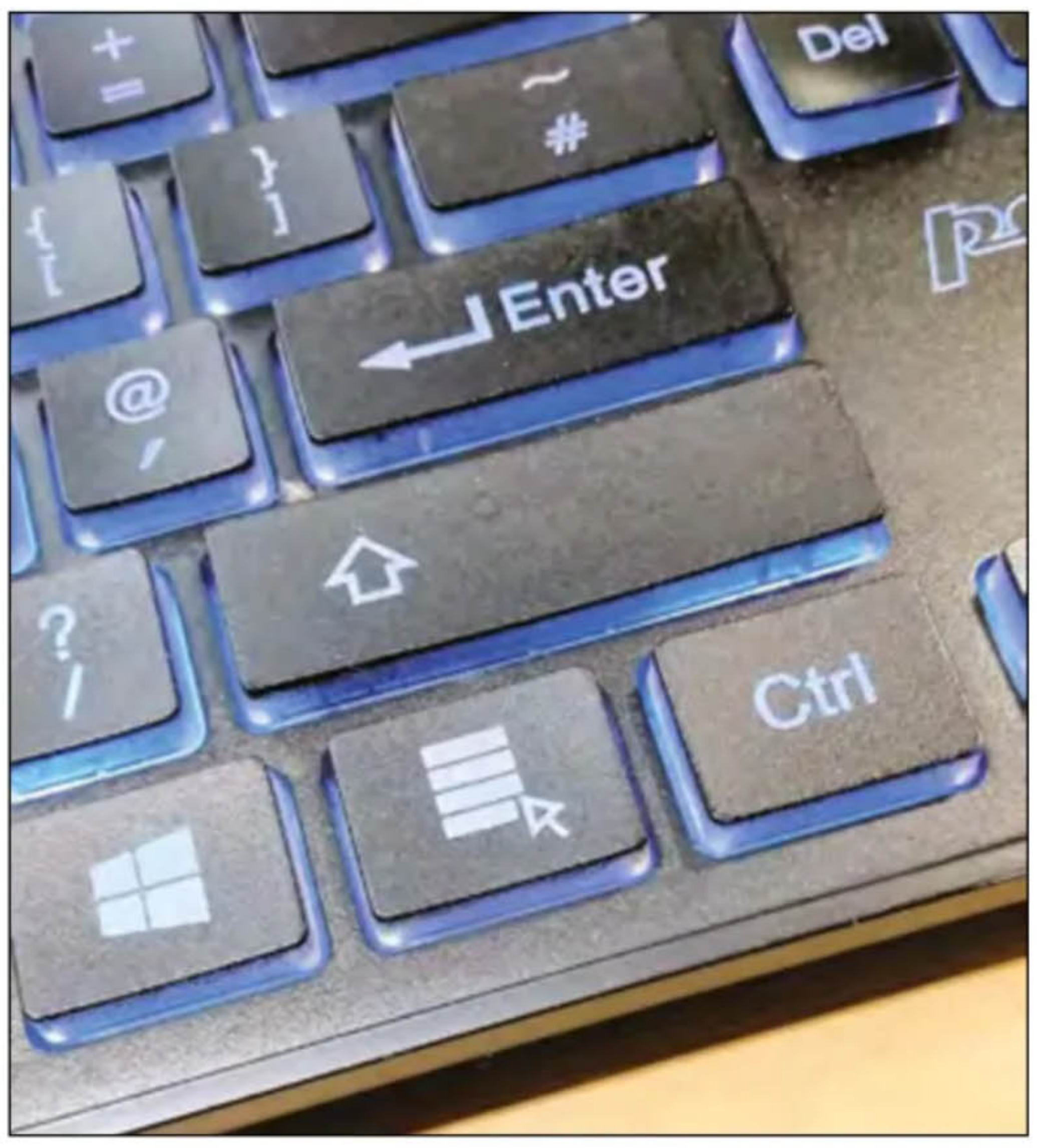
Windows Copilot in Bing now has a microphone control that allows users to voice their search queries.

management, so PC users could, for example, ask Copilot to open sound settings, instead of having to mouse-click around to find Settings/Sound in a myriad of keyboard shortcuts, menus and pop-ups. You could also ask Copilot to make a System Restore Point, and so on.

It's worth remembering that Windows already has a useful, and somewhat underrated, Search feature: you can open the Search magnifying glass icon on the taskbar (or go ⊞ + S, Bing reminds me) and simply type a search term such as 'Sound settings' or 'Create system restore', and a link to the applet will be displayed. You can also search documents or the web, or open an app this way instead of hunting for an icon or shortcut. To try it: go ⊞ + S then start to type `Notepad` for example. I must add, readers, that Copilot in Bing explained perfectly how I can insert that Windows key symbol into my copy!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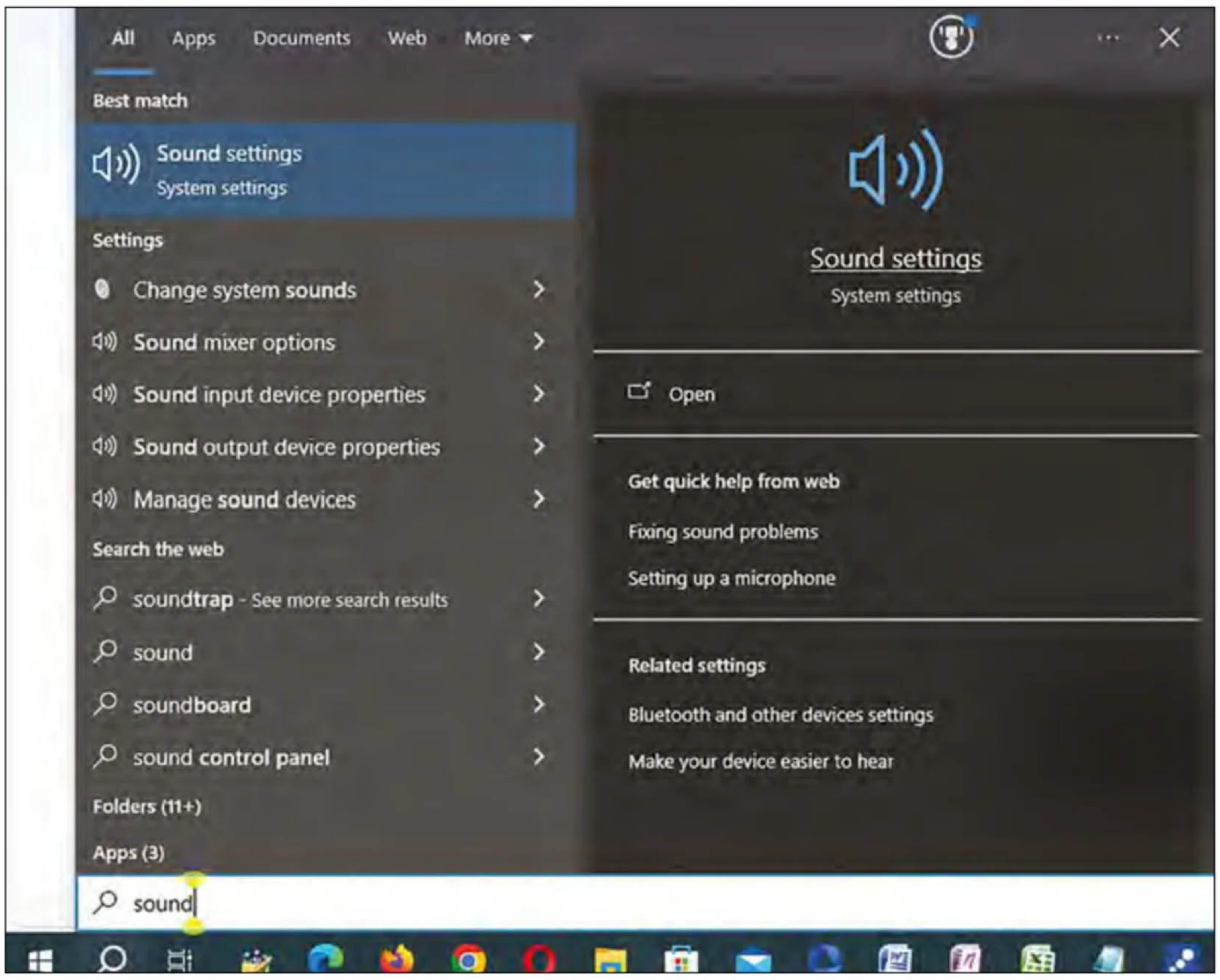
The largely redundant Menu key on a Windows keyboard is set to be replaced in the future with one that opens Windows Copilot.


All
Apps
Documents
Web
More
Best match
Sound settings
System settings
Settings
Change system sounds
Sound mixer options
Sound input device properties
Sound output device properties
Manage sound devices
Search the web
soundtrap - See more search results
sound
soundboard
sound control panel
Folders (11+)
Apps (3)
sound
Sound settings
System settings
Open
Get quick help from web
Fixing sound problems
Setting up a microphone
Related settings
Bluetooth and other devices settings
Make your device easier to hear

Using Windows Search is an easy way to find and open apps or settings. Type the Winkey + S to launch it.

Copilot 2.0 promises to take computer management to a new level and will vastly simplify life for Windows 11 users, and I must admit I'm warming to the idea. It's also understood that forthcoming Windows keyboards will incorporate a Copilot key in place of the Menu key (to the right of the space bar), a key that in all honesty I have never used in 30 years of computer ownership. (The Alt Gr key only gets a look-in when I need to type the euro symbol (€), using the 4 key on a UK keyboard.)

Advanced PC users can remap a spare keyboard button by using Keyboard Manager in the excellent Microsoft Windows PowerToys from the Microsoft Store. PowerToys has myriad handy tools and settings (including a useful cursor finder tool and more) to customise your Windows desktop. The legacy Microsoft Keyboard Layout Creator (MSKLC) tool is another way of re-purposing under-used keys or re-assigning keyboard layouts or languages (Windows 2000 to Windows 10). A free download of MSKLC is still available from: **https://bit.ly/pe-mar24-msklc**

Looking ahead, speculation by How-To Geek suggests that Windows 12 may be released at the end of this year. Little else is known, but an early screenshot is shown at: **https://bit.ly/pe-mar24-htg**

Mission Impossible

I was hoping to bring news of the first successful launch of a moonshot from Cape Canaveral since NASA's Apollo 17 departed back in 1972. Astrobotic is a private US aerospace company that has developed two lunar landers so far, starting with the 'Peregrine' which it describes as a 'small-class lander that precisely and safely delivers payloads to lunar orbit and the lunar surface. Payloads can be mounted above or below the decks, inside or outside of enclosures, and can remain attached or deployed according to their needs.'

Unfortunately, this was not to be the case. On their first lunar mission, a Peregrine lander carried by a United Launch Alliance (ULA) Vulcan Centaur rocket (itself a joint venture between Lockheed Martin and Boeing, embarking on its own inaugural flight), suffered a shut-off valve failure after a successful launch and payload separation. The damage to the lander caused a critical loss of propellant, as precious fuel was expended in stabilising the craft to prevent it tumbling out of control. At the time of writing, because solar power could not be brought online, the rest of the aborted mission is likely to be dedicated to gathering as much data as possible before power is lost altogether.

There were high hopes of success, and the payload included a lunar rover, Earthly mementoes and artefacts from various institutions – a full list of the manifest is at: **https://bit.ly/pe-mar24-astro1**

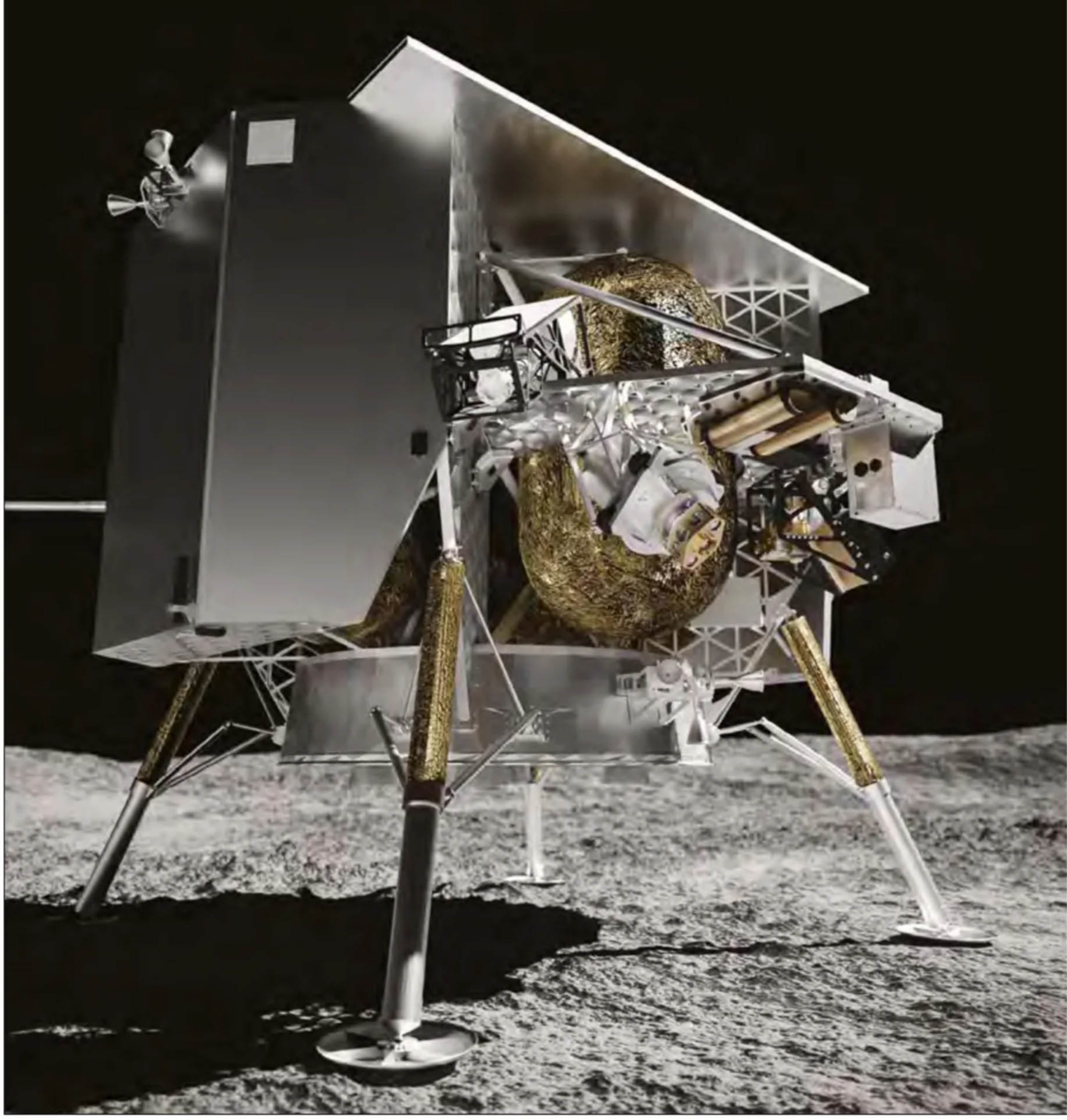
The mission failure is obviously a sad and disappointing setback, but the next mission will use a larger 'Griffin' lander with five times the capacity, intended to carry a NASA lunar rover to the Moon's South Pole. Space fans might enjoy the background YouTube video at **https://youtu.be/wXzxKScQLjw** and there's a complete *User Guide* to the Astrobotic lunar lander in case you ever want to send something to the Moon yourself – see: **https://bit.ly/pe-mar24-astro2**

Also expected to launch on board another Vulcan Centaur rocket will be Sierra Nevada's Dream Chaser re-usable space plane (see last month), another privately funded craft, which is slated for a first flight in April, landing back on Earth using a normal runway.

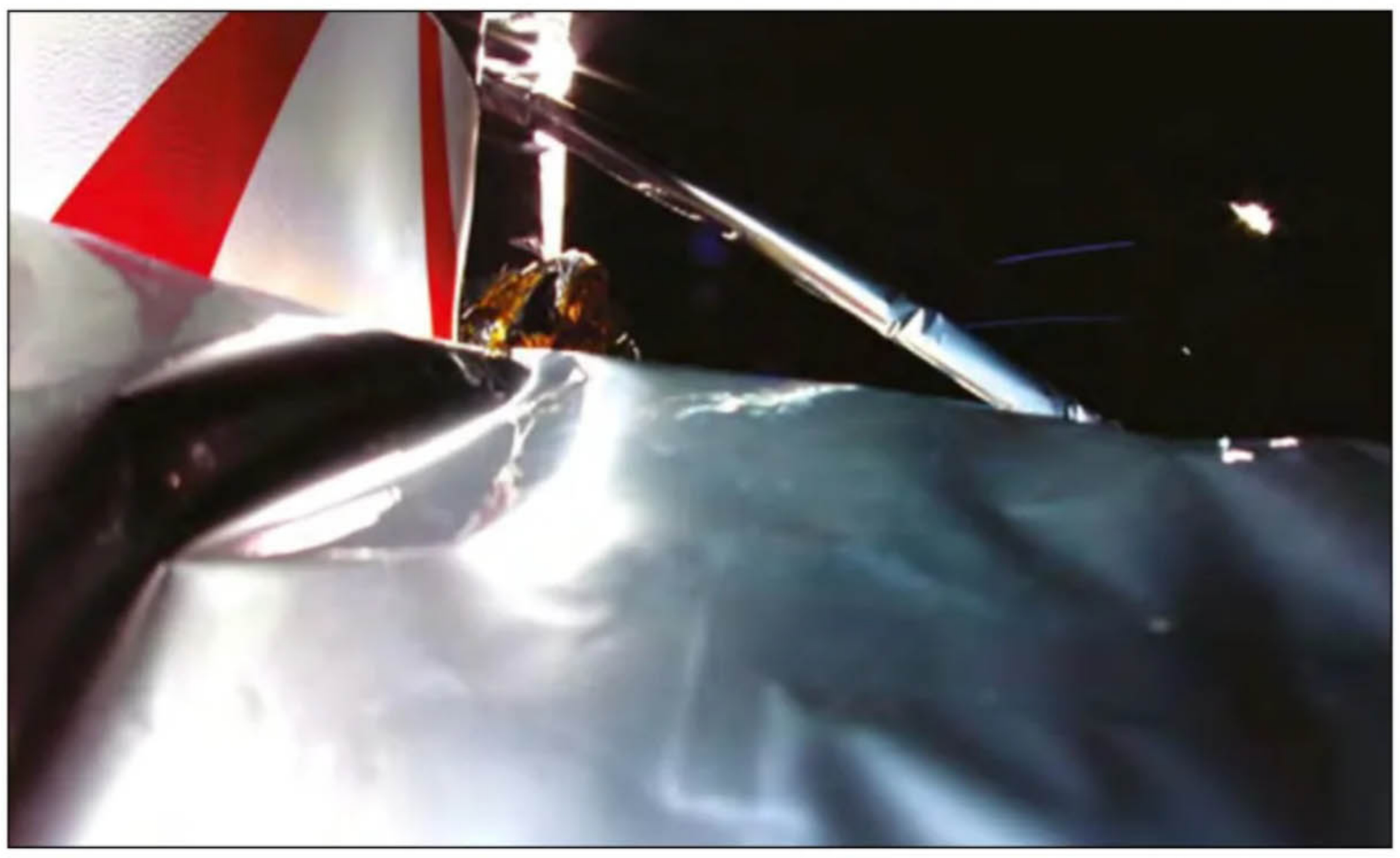
Shooting for the moon

NASA's own moonshot plans revolve around Artemis (the Greek mythological twin sister of Apollo), a program that aims to land the first woman astronaut on the moon. An Orion uncrewed capsule, carried into orbit by the new Space Launch System (SLS) heavy lifter, had its first successful test flight around the moon and splashdown at the end of 2022 (a 25-minute onboard video of Orion's re-entry is at: **https://bit.ly/pe-mar24-nasa**

The next mission, Artemis II, will be a fully crewed lunar fly-by, but development delays have seen this postponed to no earlier than September 2025. A 2-crew moon landing (Artemis III) would then see the first humans land on the lunar south pole. Future concepts include building



Artist's impression of the Peregrine small-class lander on the moon.



Crumpled insulation pictured by an onboard camera on the Peregrine lander suggests a propulsion system failure. (Image: Astrobotic)

The X-37B is a secretive unmanned reusable space plane undergoing extensive trials for the US military. (Image: Boeing)

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A quick snap inside the Honda e:Ny1 battery electric vehicle, with large centre touchscreen controlling many functions.

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a small lunar 'base camp' that would allow astronauts to live there for several months at a time. China and Russia hope to do the same between them.

More enigmatic is the secret American X-37B, a mini space-shuttle type of craft developed by Boeing for the USAF that is intended to fly in low earth orbit. The unmanned re-usable glide vehicle, about a quarter the size of the original Space Shuttle, would enable space-borne experiments and apparatus to be launched and returned to Earth. Seven, mostly classified missions have flown so far, the latest launching in December 2023. Previous missions saw a record-breaking X-37B remain in orbit for more than 900 days. China is also experimenting with reusable space planes: its *Shén Lóng* (Divine Dragon) space plane has been launched three times, with the second flight possibly releasing a satellite into space. Amateur astronomers noted six mysterious objects being released by the third flight, some of them emitting intermittent signals. Details of the mystery flights remain secret.

Your mileage may vary

My trusty petrol-powered car was collected for an annual service a few weeks ago, and the local garage usually drops off a courtesy car for my convenience. This year, it was not a small and dinky Honda Jazz (Fit) as before, but a brand new £45,000 ($55,000) Honda e:Ny1, a Chinese-built battery electric vehicle which had just 70 miles on the clock. It would be rude not to try it out, I mused, but after taking one look at the LCD dashboard I decided to give it a miss. Still, the garage insisted on taking me for a spin (part of a soft-shoe sales pitch, possibly), and as we hummed along some country lanes I was given a taste of its slingshot acceleration! It was freezing weather outside, and with the heated seats and cab heater going full blast, in under two hours the battery had fallen to 70%, my driver told me. (I calculated that two hours of driving my own car with a full tank would leave me with roughly the same amount of fuel, but at least I could easily fill it up again.)

The e:Ny1 dash is dominated by an excellent 15.1-inch central touchscreen, with all-round cameras and satnav that I found to be extremely impressive, although when it comes to turning down those heated seats, it's a case of tapping several times a small icon in one corner of the touchscreen (no on/off here – there are three power levels). To my mind, it was a serious distraction while driving, as there is no haptic feedback and it's too easy to 'mis-key' the icons anyway, especially if driving on our bumpy country roads. I believe the Ford Motor Co. once said, 'Don't build a car with gritty switches' because they give a bad impression of build quality. Honda's quality is undoubtedly superb, but, not withstanding the eye-watering cost, give me proper pushbuttons any day, even gritty ones!

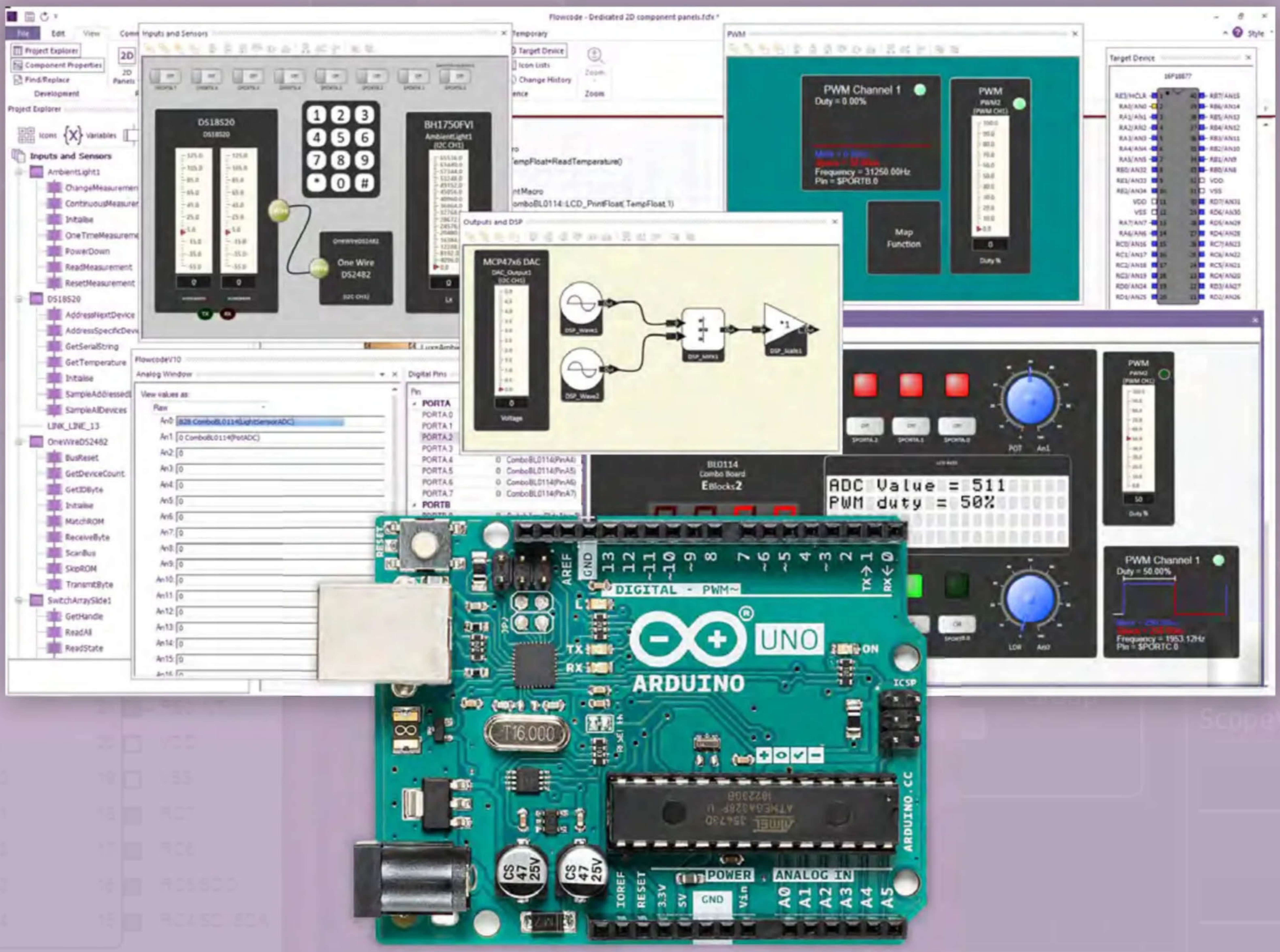
Two more Chinese brands of electric vehicle are set to enter the UK market by the end of this year. The Seres 3 will go head-to-head with MG, while the Skywell ET-5 is a mid-size SUV. The Skywell website made me dizzy; you can look at it here: **https://skywell-europe.com**

At first glance the car looks remarkably like the Honda.

Last this month, I spoke too soon when I said that my 12-year old Synology NAS was still supported by the manufacturer (February 2024, *Net Work*). A few days later they notified me that security updates for its legacy operating system (DiskStation Storage Manager V6) were finally being discontinued, and my model can't be upgraded. At least I have a breathing space as the deadline isn't until 1 October this year.

That's all for this month's *Net Work*. The above links are ready-made for you in our advert-free website at **electronpublishing.com** – just follow the 'Blogs' link at the top, and details of this month's Microchip competition will also be found online.

The author can be reached at:
alan@epemag.net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The Fox Report

Barry Fox's technology column

The very best way to buy online

There is much talk of revitalising local high streets. Not everyone can use the Internet – or wants to use it – for online shopping. Buying fashion, food or artistic designs is much better done in person. Purchasing big box electricals, such as TVs, audio equipment, fridges and washing machines online can be iffy too because returning large and fragile goods, if faulty or not as described, is a huge headache.

Some good, some not so good

Until recently, Currys had the big box market sewn up, but has now inexplicably attacked its own throat by making it no longer possible to check stock and pay by phone for collection or delivery. 'If you need to speak to someone, you can call us on 0344 561 0000' assures its website. Try phoning and hear for yourself the recorded message you get!

On a brighter note, Richer Sounds sells big box audio and TV from high street stores and also online. I recently bought some Hi-Fi gear online for free delivery from them and it was a Grade A experience.

But, let's face it, the days of going down London's Tottenham Court Road to buy specialist electronics and components are long gone, for ever. Whether we like it or not, it will usually be much easier and cheaper to buy them online, often direct, or near direct, from the makers in China. If goods are faulty the online vendor will usually refund without quibble. (Top tip: select a vendor who ships from a UK address to avoid the wait for a slow boat from China.)

Inevitably, the online shopping experience sometimes breaks down and some months ago I detailed here what can go wrong if the carrier delivers goods to an incorrect address – in my case Royal Mail with a clearly fraudulent Proof of Delivery note. (Incidentally, and in light of national outrage at the Post Office's treatment of sub-Postmasters, an MP is now asking Royal Mail about delivery fraud.)

Dealing with eBay

The FOS (the Financial Ombudsman Service, which is the arbitrator for the FCA (Financial Conduct Authority), which regulates the financial services industry in the UK) has now provided some very valuable practical guidance for anyone experiencing difficulties with eBay.

eBay's website in the UK currently talks reassuringly about its eBay Money Back Guarantee, which aims to protect and reimburse buyers against, among other things, non-delivery of goods or services and faulty items purchased via eBay's online marketplace. If things go wrong with an eBay online trade and someone complains to eBay, eBay reassures that 'if we're unable to resolve your complaint, you may be eligible to escalate it to the UK Financial Ombudsman Service (FOS)' – see:

https://bit.ly/pe-mar24-ebay1
https://bit.ly/pe-mar24-ebay2

But it ain't necessarily so

After many months of my persistent correspondence and discussion with the FOS, the FOS has helpfully and clearly explained the real-world situation. So, to summarise what a lot of people may *not* know:

- eBay in the UK comprises two quite different and separate entities 1) eBay Marketplace, which is eBay (UK) Limited, accessed via the **eBay.co.uk** website and 2) eBay Commerce UK Limited.
- eBay Commerce UK Limited (ECUK) provides payment services for sellers on the eBay platform and is regulated by the Financial Conduct Authority (FCA). The Financial Ombudsman Service (FOS) can investigate complaints but for payment services only.
- The eBay Money Back Guarantee scheme managed by eBay (UK) Ltd covers purchases made via eBay's online marketplace eBay (UK) Ltd at **eBay.co.uk** and is not regulated by the FCA and is *not* answerable to the FOS.

The FOS confirms: 'eBay (UK) Limited is not a regulated financial firm which means that this service (FOS) can't consider complaints against it'. So, the FOS cannot consider complaints about the eBay Money Back Guarantee because it is managed by unregulated eBay (UK) Ltd. The 'pith and marrow', as legal eagles like to say, is that 'eBay (UK) Limited aren't regulated and it is this firm that manages the Money Back ' Guarantee scheme'… and the FOS isn't 'able to consider' a customer complaint. Put another way, if you try to complain to the FOS about eBay's Money Back Guarantee scheme, you are bang out of luck.

Hence, I repeat my online trading tip. If you are buying online from anywhere and things go wrong, with goods missing or faulty, don't waste time on escalating rejected complaints through multi-stage, marking-own-homework procedures. Simply use the Chargeback system run by the credit card companies.

Expect one knee-jerk rebuttal back from the other side and be sure to contest it. But if you have right on your side, and stick to your guns, you will most likely hear nothing more, and see your money come back home safe to your card.

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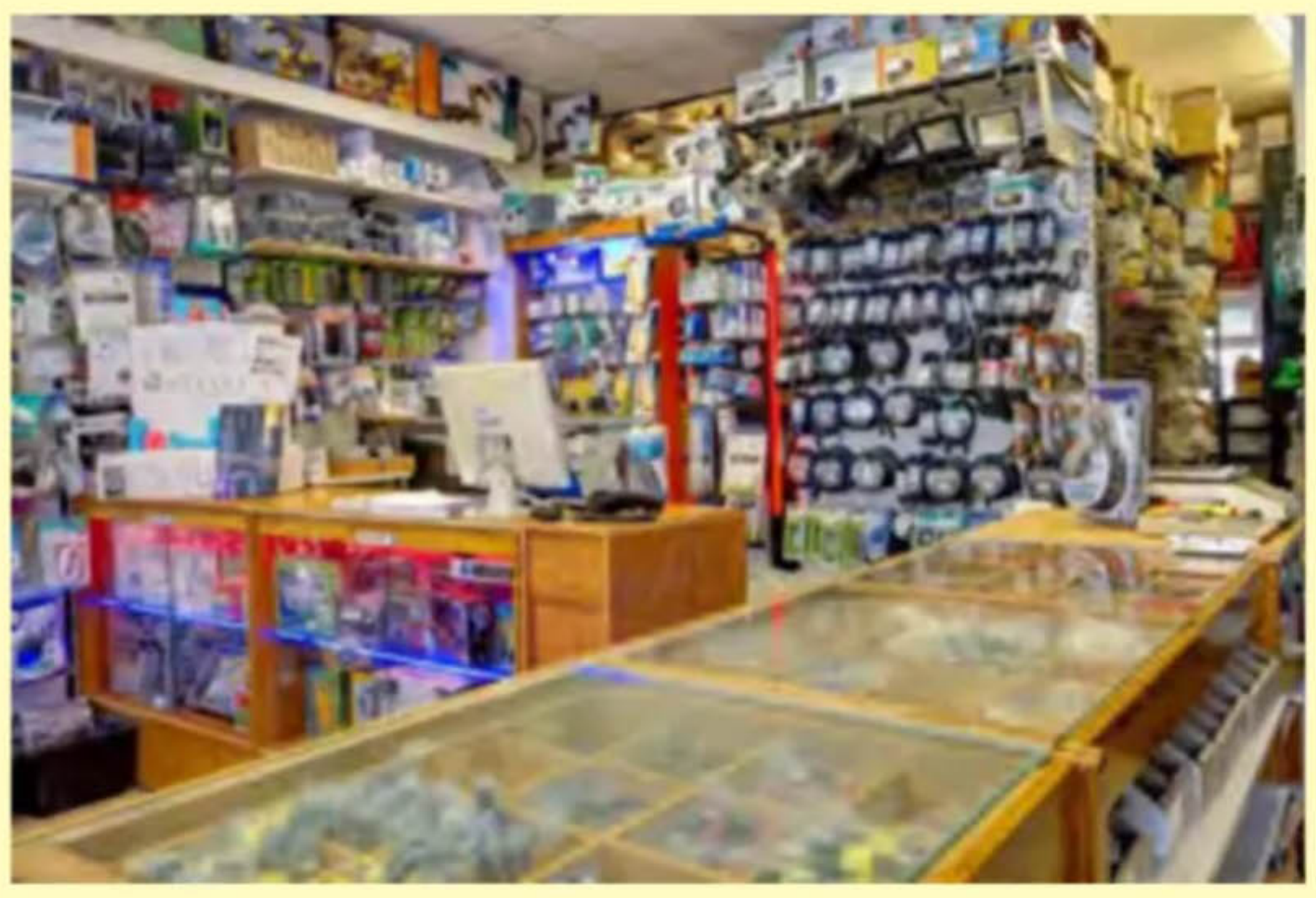

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DIGITAL VOLUME CONTROL POTENTIOMETER

By Phil Prosser

We got tired of volume control potentiometers going scratchy after just a few years, and very poor balance at low volumes. This drop-in replacement uses a digital IC, so it tracks exceptionally well and will give top performance for decades. The SMD version fits in the space occupied by most regular pots, while the through-hole version does a similar job but is a bit easier to build.

We have had to replace volume controls in our prized equipment too often due to them going 'noisy'. Recently, a reader wrote in with that exact same problem; so we know it affects many people.

In one spectacularly loud failure, a ground tab on the volume pot for my work stereo failed, resulting in that channel running flat-out all night, to greet co-workers at full blast the next morning!

The gauntlet was thrown down recently when building a remote volume control. The motorised pot literally failed out of the box, the crimped-on tabs were loose (we know others have experienced this failure mode).

There must be a better solution! Why aren't there pot-sized volume digital controls that use some of the excellent electronic volume control ICs with a digital rotary encoder? Well, now there are!

The original concept for this project was a straight-out replacement for a volume pot. I was asked the innocent question: 'If you have a PIC in there to control the volume IC, why not have IR remote control as well?'. As it turned out, that was not too difficult to provide.

The resulting SMD design is a very modest size at just 25mm wide by 36mm deep. It's just a little larger than a typical dual-gang log pot, as shown in the photos.

While this small size is clearly a boon in many situations, we knew that some readers would be apprehensive about building it. Although the board is quite packed, none of the parts are especially small. Still, it wasn't too much work to come up with a through-hole equivalent design, so that is what I did, which means we have two options for you.

I checked its performance and found it to be close enough to the SMD version that nobody would notice an audible difference. So if you have room to fit a larger board, it is certainly an option. Its circuit is identical; it simply uses physically larger components on a different

Features

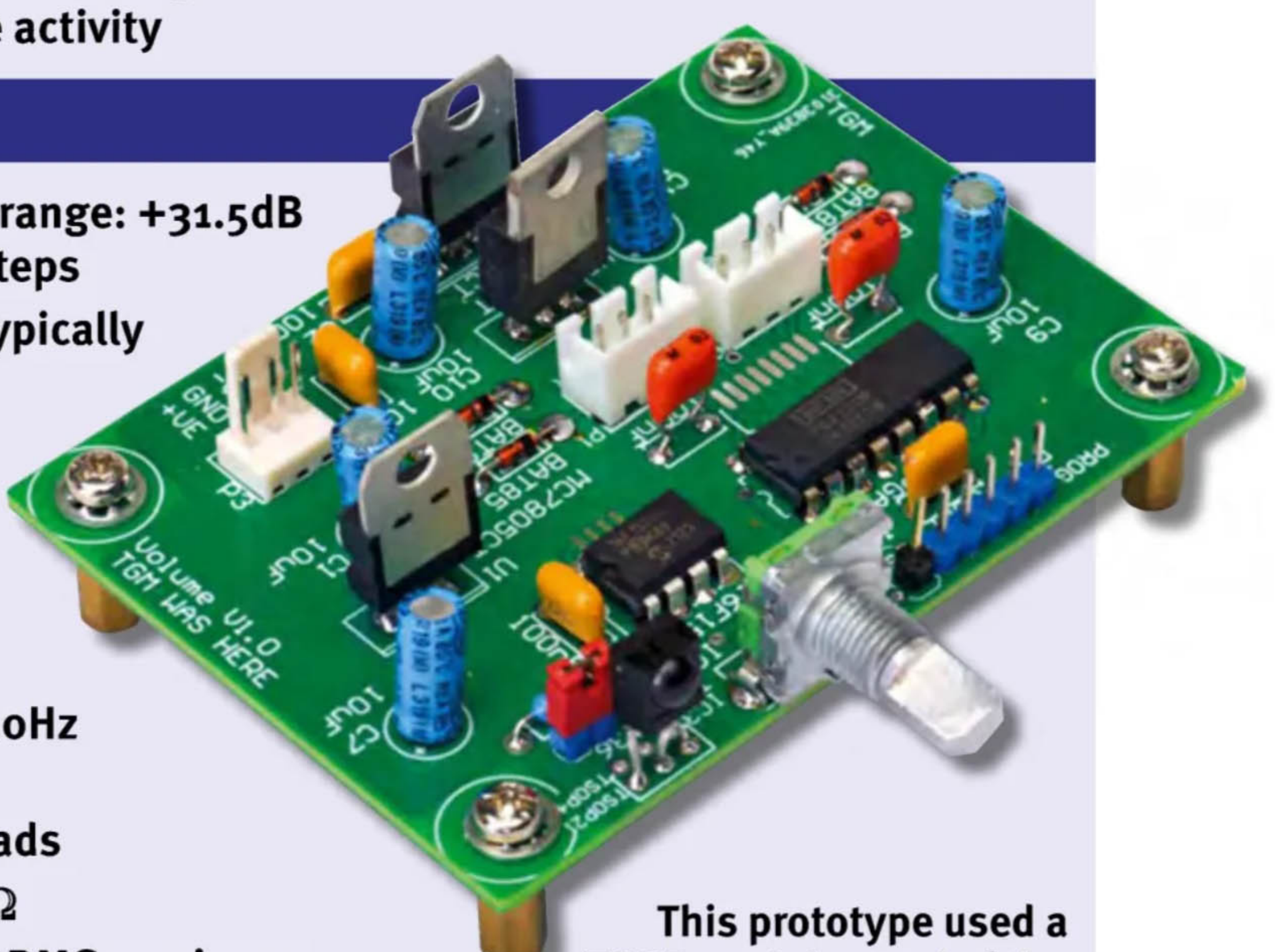
- ☑ Based on the PGA2311UA stereo digital volume control IC
- ☑ Two independent channels (expandable up to four, six or more)
- ☑ Automatically remembers the last volume setting
- ☑ Volume adjusted by a rotary control on the front panel or universal IR remote control
- ☑ Mute function (remote control only)
- ☑ Soft start at power-up
- ☑ 'Clickless' design
- ☑ Controlled by a PIC16F15214 microcontroller and TSOP4136 IR receiver
- ☑ Operates from a preamp power supply from ±8V to ±30V
- ☑ Optional LED indicator showing IR and volume change activity

100nF
TGM
Volume V1.0
78L05

The SMD version of the Digital Potentiometer is a little larger than a coin and just wide enough for the rotary encoder and IR receiver to fit. And for those who don't want to squint while building it, there's the larger through-hole version shown below.

Specifications

- ☑ Gain and attenuation range: +31.5dB to –95.5dB in 0.5dB steps
- ☑ Channel gain match typically within ±0.05dB
- ☑ 0.0002% distortion at 1kHz (using the -UA version of the IC) – see Fig.1
- ☑ Frequency response: essentially flat from 20Hz to 20kHz
- ☑ Able to drive 600Ω loads
- ☑ Input resistance: 10kΩ
- ☑ Signal handling: 2.5V RMS maximum input level
- ☑ Output level: up to 2.5V RMS (7.5V peak-to-peak)



This prototype used a TSOP2136, instead of the recommended TSOP4136, which is why the IR receiver is shown mounted on the outer set of pads. (Refer to the text.)

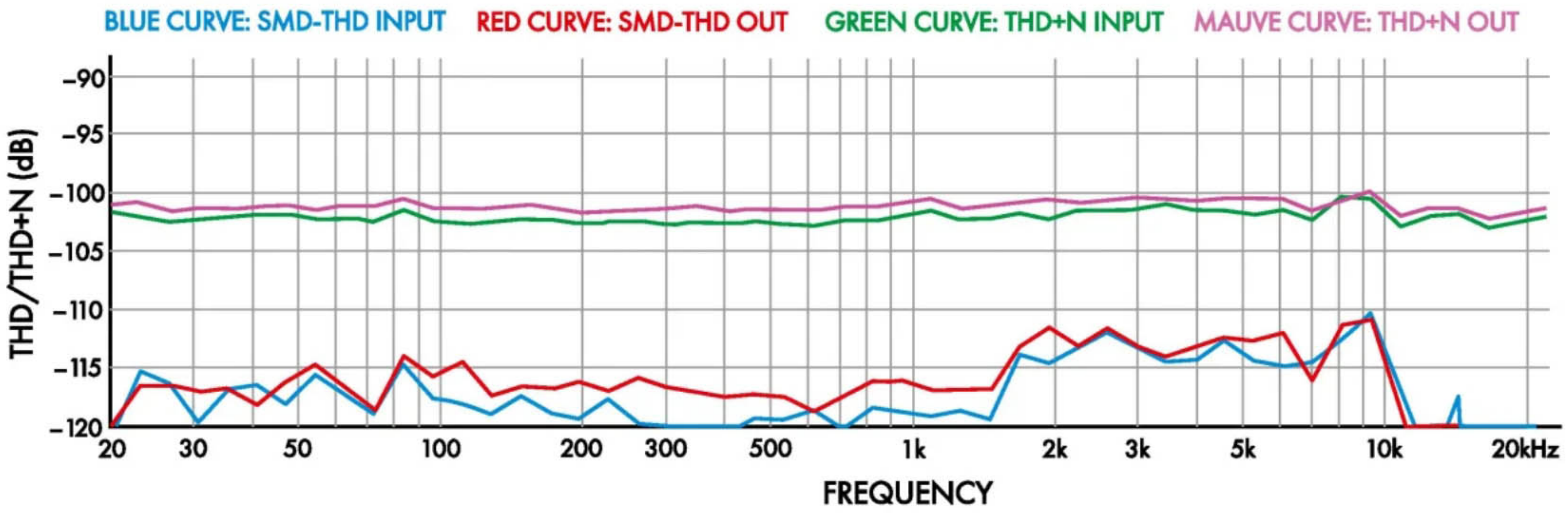


Fig.1: THD and THD+N vs frequency plots for the Digital Pot for both channels – nothing to see here, folks! Move along! You'll get similar or better performance from this design compared to a regular, passive potentiometer.

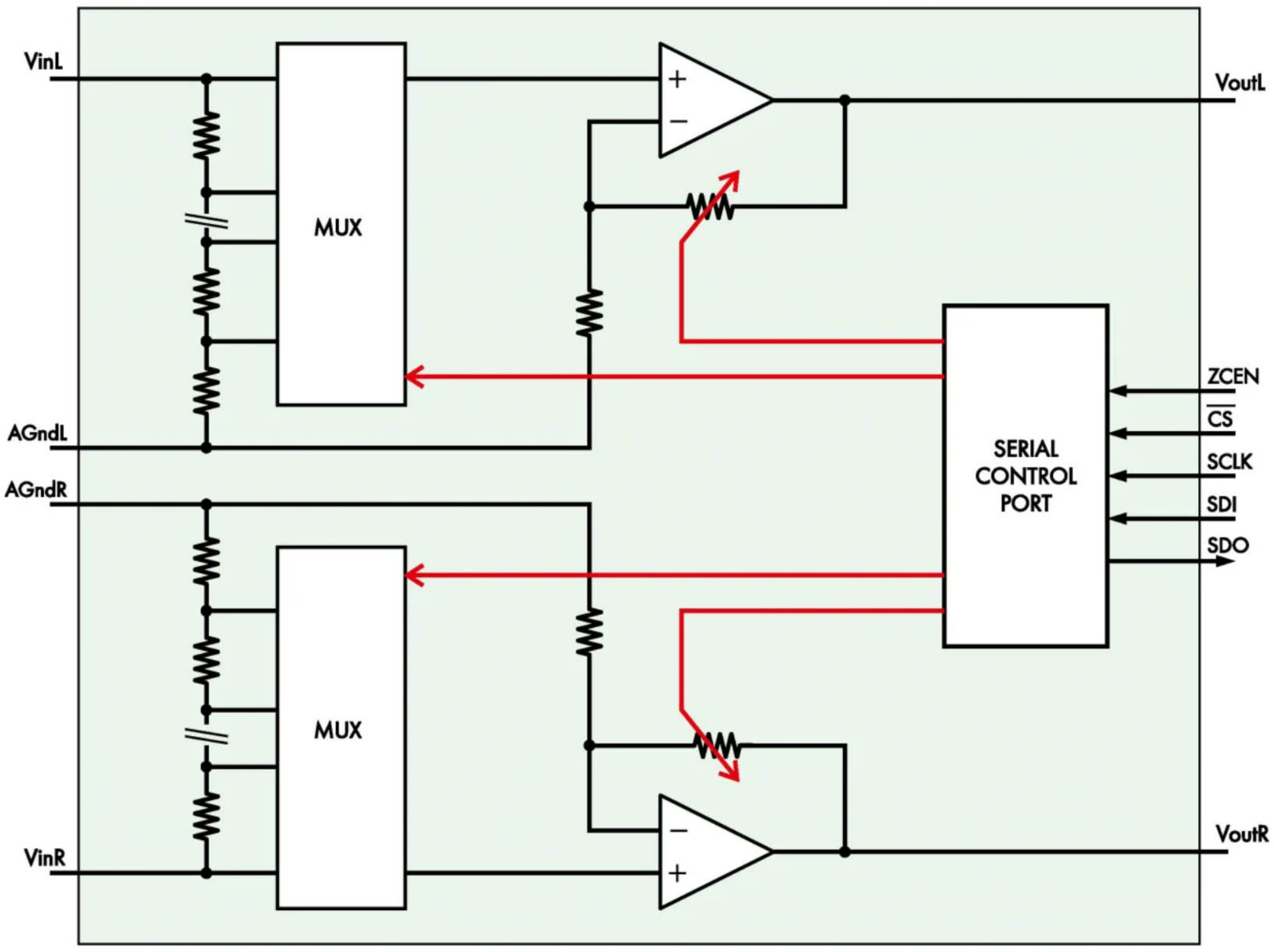


Fig.2: this shows what is inside the PGA2311 (and PGA2310, PGA2320) ICs. The switched resistive attenuator and switched feedback in the output amplifier allow for a wide range of gain and attenuation settings.

board that measures just 79mm wide and 57mm deep.

Performance and IC choice

The specifications panel and Fig.1 show the performance of the prototypes. There's so little noise and distortion that it certainly won't be audible and will not affect the audio quality of even the best amplifiers.

We measured the distortion of five prototypes, and all were in the 0.0002-0.0003% distortion region, which is close to the measurement limit of our test equipment.

The heart of the project is the PGA2311 Volume Control IC from Texas Instruments. The PGA2320 or PGA2310 can also be used with identical performance, but those versions are much more expensive for reasons we cannot explain, other than they can operate from higher ±15V supply rails compared to ±5V.

You need to use one of the PGA2311 chips with a UA suffix to get the specified performance. The obsolete CS3310 will also work just fine, and they are still reasonably easy to find on the grey market (eBay or AliExpress).

Still, all of those options will give acceptable performance. In short, we are confident that you will find one volume IC or another to fit on your board, even in these times of IC shortages.

The PGA2311 contains a resistor network and analogue switch along with switched resistors in the feedback network of the output buffer amplifier, as shown in Fig.2. This allows the device not only to attenuate but also to provide up to 31.5dB gain. Pay attention to this; turning it up too high when you don't have an input signal leads to a loud surprise!

This IC is very quiet, so do not expect to hear hiss or noise to warn you that the volume level is high.

While these ICs can provide up to 31.5dB gain, we limited the Electronic Volume Control gain to +10dB. An alternative firmware allows you to run up to +31.5dB, but be warned that this is an awful lot of gain.

Circuit details

The *Digital Pot* circuit is shown in Fig.3; there is not much to it. There are a couple of things on the board beyond IC2 (the PGA2311 or equivalent): the PIC microcontroller (IC1), rotary encoder (RE1), IR receiver (IRR1) and some power supply components.

The audio performance of this project is almost entirely determined by the PGA2311, as there is nothing else in the signal path. The left channel signal is fed in via pin 1 of CON2. It goes straight into IC2's input pin 16, exits from its output pin 14 to pin 2 of CON2, for feeding to the amplifier (or whatever is downstream). The other channel is routed similarly, via CON1.

We have included input protection with a BAT54S dual schottky diode (or a pair of BAT85s on the through-hole version) from each input pin to the supply rails. This way, if the input is over-driven, the diodes will conduct and help to protect the PGA2311 from damage.

We decided not to include DC-blocking capacitors on either the input or output. The reason is that four bipolar capacitors would have added probably 20% to the PCB size. We expect these will be in your signal chain already (after all, if you're replacing a mechanical pot, you won't be applying DC to it) and the output offset voltage of the PGA2311 is only 0.25mV at 0dB gain.

If you have DC in your signal chain, you will need to include a blocking capacitor in series with the *Digital Pot* – we recommend a 10μF 25V bipolar electrolytic capacitor. You can also use two regular 10μF 25V electrolytics connected in series, negative-to-negative or positive-to-positive. Both options will have no noticeable effect on the audio.

With the outputs, we are assuming that the *Digital Pot* will drive short cables to your amplifier or follow on circuitry. The PGA2311 can drive 600Ω loads and has a short-circuit current of 50mA, so it is unlikely to misbehave if presented with an unusual load.

Still, if you intend to drive long cables with this, add a 100Ω resistor in series with each output. A convenient place for this would be at your output socket.

Controller

If the PGA2311 is the heart of this design, the 8-pin PIC16F15214 is the brain. The main job of the software running on this PIC is to monitor the rotary encoder and, if it is turned, send a signal to IC2 to adjust the volume appropriately.

It also looks for signals from the infrared receiver and, if it receives a valid signal from a remote control, also figures out what command to send to IC2 in response. We'll have more details on how the software works later.

Power supply

IC2 operates from ±5V supply rails. To allow a wide variety of amplifier/preamplifier supply rails to be used to run this board, we have onboard 78(L)05 or 79(L)05 regulators.

This means you can power the *Digital Pot* from split supply rails from ±8V to ±30V, which should suit most applications. A typical preamp will have such rails available, and some smaller amplifiers without preamps might too.

In keeping with the design concept, the power supply is very simple. The PGA2311 has a typical power supply rejection ratio (PSRR) of 100dB at 250Hz, so any noise that the basic linear regulators let through will not realistically affect performance. Of course, you could 'roll your own' low-noise ±5V DC supply and delete the regulators as an upgrade.

Suppose you want to fit the *Digital Pot* into a power amplifier with only split supply rails above ±30V. In that case, you could connect 5W zener diodes in series with the two supply rails to drop them into the *Digital Pot's* acceptable range. It only draws a few tens of milliamps, so that should work for just about any amplifier. Just ensure the zener polarities are correct (anode to pin 1 of CON3; other cathode to pin 3).

If you use the PGA2310 or PGA2320 devices, you also have the option of increasing the analogue supply rails to as high as ±15V. This will make no difference in the vast majority of applications, but the choice is there. The simplest way of doing this is to drop in 78(L)15 and 79(L)15 regulators for REG2 and REG3, respectively. Don't change REG1 to a higher voltage type.

Firmware

The source code and HEX file for this project are available for download from the March 2024 page of the PE website: **https://bit.ly/pe-downloads**

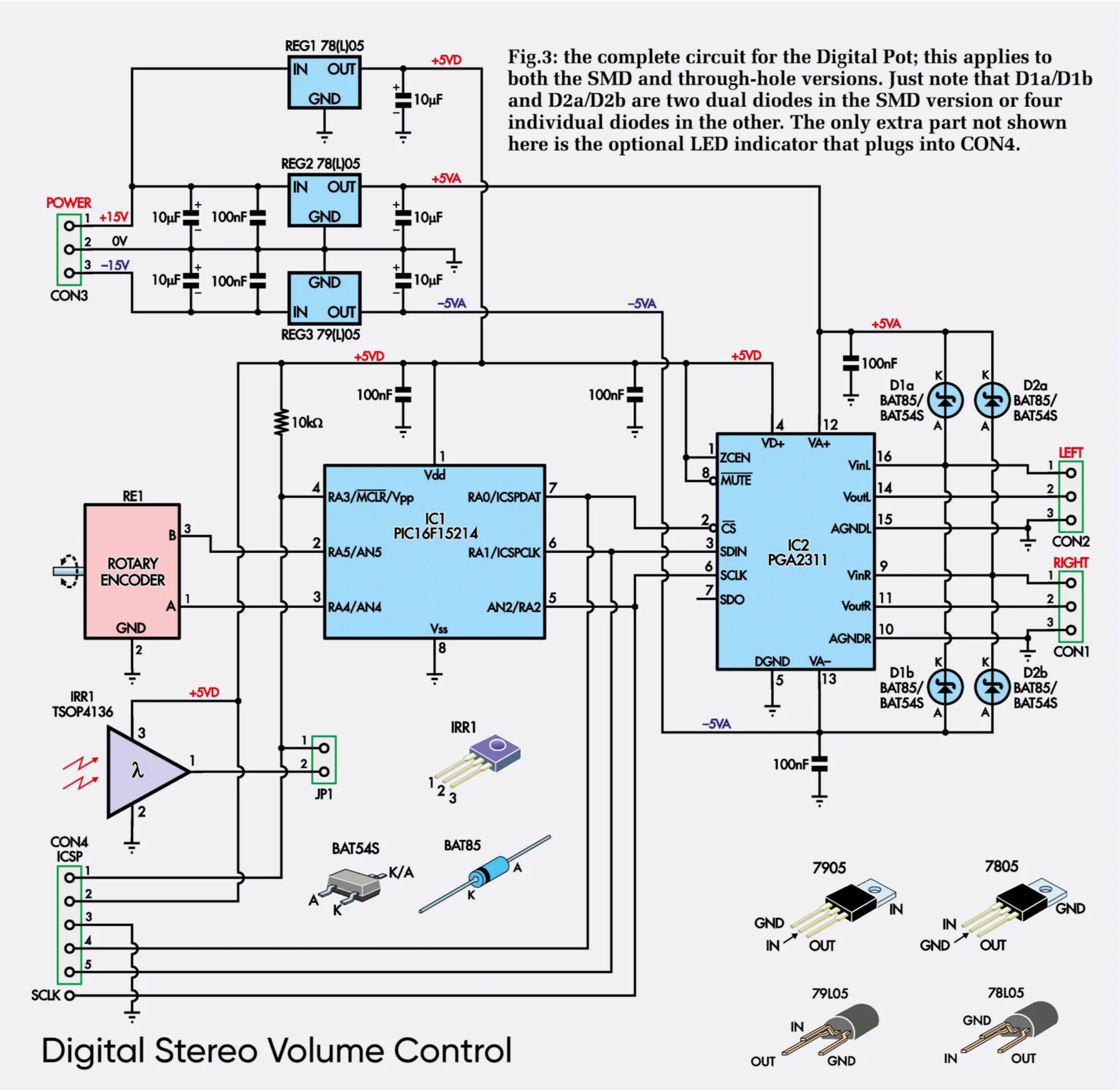


Fig.3: the complete circuit for the Digital Pot; this applies to both the SMD and through-hole versions. Just note that D1a/D1b and D2a/D2b are two dual diodes in the SMD version or four individual diodes in the other. The only extra part not shown here is the optional LED indicator that plugs into CON4.

REG1 78(L)05
REG2 78(L)05
REG3 79(L)05
IN
OUT
GND
+5VD
+5VA
–5VA
10µF
100nF
10kΩ
POWER
+15V
0V
–15V
CON3
RE1
ROTARY ENCODER
IRR1
TSOP4136
λ
JP1
CON4
ICSP
SCLK
IC1
PIC16F15214
Vdd
Vss
RA3/MCLR/Vpp
RA5/AN5
RA4/AN4
RA0/ICSPDAT
RA1/ICSPCLK
AN2/RA2
IC2
PGA2311
VD+
VA+
ZCEN
MUTE
CS
SDIN
SCLK
SDO
VinL
VoutL
AGNDL
VinR
VoutR
AGNDR
DGND
VA–
D1a
D2a
D1b
D2b
BAT85/
BAT54S
K
A
LEFT
RIGHT
CON2
CON1
BAT54S
BAT85
K/A
7905
7805
79L05
78L05
Digital Stereo Volume Control

On boot-up, the software configures several registers to set the processor clock speed to 4MHz, much lower than the maximum, and starts a timer for measuring IR signals. It then loads the saved volume level and remote control configuration from flash memory, checks to see if the user wants to change the remote code and, if not, ramps the volume from zero to the last used value over a couple of seconds.

It then monitors the rotary encoder and IR input ports for action, and if anything happens, decides if the rotary encoder is being turned up or down or reads the IR stream to see what code was transmitted.

The software writes a new volume level value to the PGA2311 IC if required. Then, if there are no changes for about 10 seconds, it saves the new volume level to the flash memory.

Modulated infrared signals are received by the TSOP4136, which includes an IR detector, 36kHz bandpass filter and output driver. The result is a digital serial stream including intentional signals from your remote control and also ambient light noise.

Noise will include ‘signals’ from lights, the sun and other IR remotes in the room. The IR receiver’s internal bandpass filter is not 100% effective at blocking this noise, but it helps a lot by reducing it to a manageable level.

While a little old now, Philips RC-5 IR codes are prevalent, and virtually all universal remote controls can generate them. RC-5 IR transmissions each contain 14 bits of data. That’s broken down into five address bits (32 possible values for TV, VCR, DVD, receiver and so on) and six command bits (64 possible values).

The stream commences with two start bits and a ‘toggle’ bit that inverts with each subsequent command. The data is ‘Manchester encoded’, a clever way of sending a string of ones and zeros on a serial line while embedding a clock signal into it. Our PIC reverses this scheme to decode the serial stream of data from the TSOP4136; more detail on this is provided in the ‘IR Signal Decoding’ panel.

The PIC microcontroller untangles all this to extract commands from the remote and change the volume or toggle the mute status.

PCB design method

We thought it might be interesting to show what we do when designing such a tightly packed board and how we are sure it will all fit. Fig.6 is a 3D rendering of the PCB from Altium during the design phase. Compare this to the actual prototype; it’s pretty close.

This depends on us entering the right models for every component, but you only need to do this once. After that, we can run interference

IR Signal Decoding

With Manchester encoding, a logic one is transmitted as a high-to-low transition, while a ‘0’ is a low-to-high transition – see Fig.4. As transmission starts with a one bit, we know that there is a high level, then a low level, at the start of every transmission.

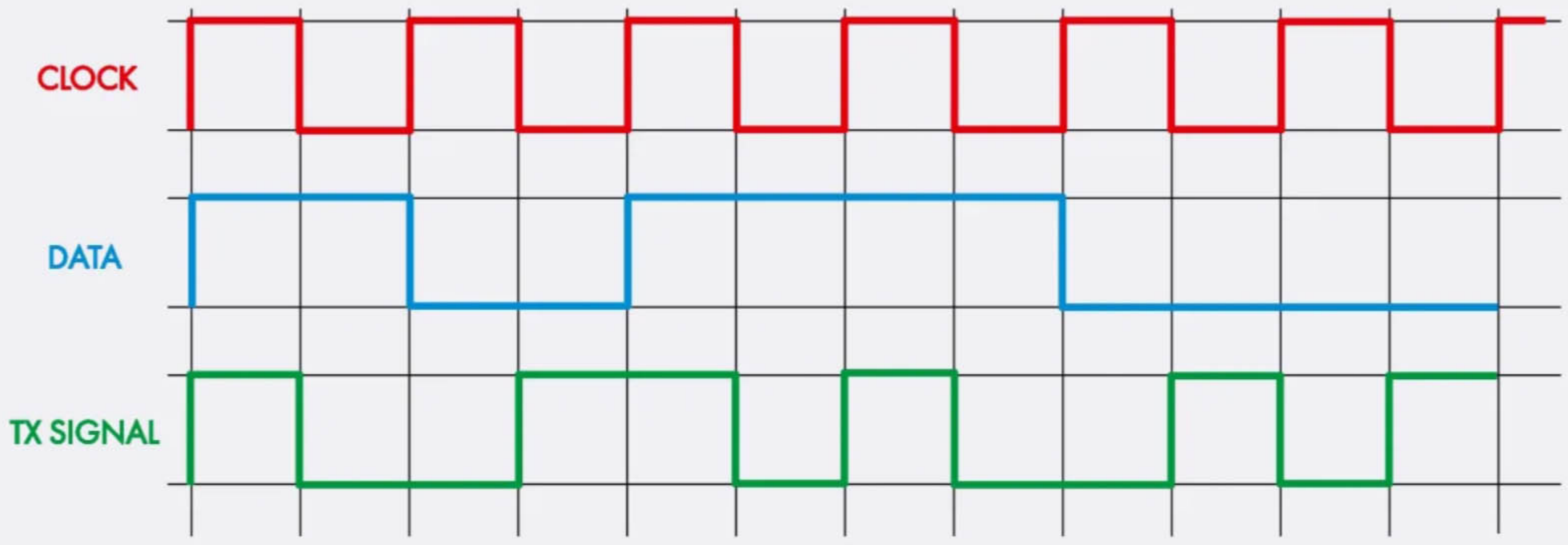


Fig.4: the Manchester Encoding scheme used by the RC-5 remote control scheme. This encoding results in no DC component, a well-defined frequency range, and the ability of a receiver to work out the clock rate from the serial data stream.

The decoder described here works well and is a good example of a simple state machine. Let’s start by listing what we know:

- A one is encoded as a period of no IR signal for 890μs (nominally), followed by an IR signal for the same time; zero is the reverse. We need to allow for some variation in the transmitter’s clock and thus periods (say ±10%).
- The IR level will never remain the same for much less than the nominally 890μs period, or much more than 1780μs if a zero follows a one or a one follows a zero.
- We are looking for 14 bits of data.

The state machine states, shown in Fig.5, are as follows.

A Clear any stored value and wait for an IR signal to be present. Set the first bit to one (we know this is true if it is a valid signal) and go to state B.

B We are receiving a one. Measure the time until the IR signal stops. If this was too short (say, less than 890μs minus 10%), this is noise; go to state A.

↻ if the time was short (closer to 890μs than 1780μs), we have just received another one. Store this and go to state C.

↻ if the time was long (closer to 1780μs than 890μs), then we are receiving a zero. Store this and go to state D.

↻ if the time was far too long (more than 1780μs plus 10%), this is noise, so go to state A.

C We just received an IR pulse starting with a one after having already received a one (there is no IR signal just now). Measure the time until we see an IR signal again.

↻ if we see it too soon, this is noise; go to state A.

↻ if the time was short, that is to be expected; store the bit and go to state B.

↻ if the time was longer than that, this is noise; go to state A.

D We just received a zero; there is no IR signal now. Wait until the IR signal starts again.

↻ if we see no IR for too short a time, this is noise; go to state A.

↻ if we see no IR for a short time, we have just received another zero. Store this and go to state E.

↻ if we see no IR for a long time, we are receiving a one. Store this and go to state C.

↻ if there was no IR for longer than that, this is noise; go to state A.

E We just received an IR pulse for a zero after a zero (there is an IR signal present now). Measure the time until we see no IR signal again.

↻ if this is less than a short pulse, this is noise; go to state A.

↻ if we see no IR for a short time, that is to be expected; go to state D.

↻ if we see no IR for longer than that, this is noise; go to state A.

If the software receives all 14 valid bits using the above method, it is considered a valid command and processed, then it returns to state A, ready to receive another command. Otherwise, it throws the data away as it is considered noise. Fig.5 overleaf shows this as a ‘state diagram’.

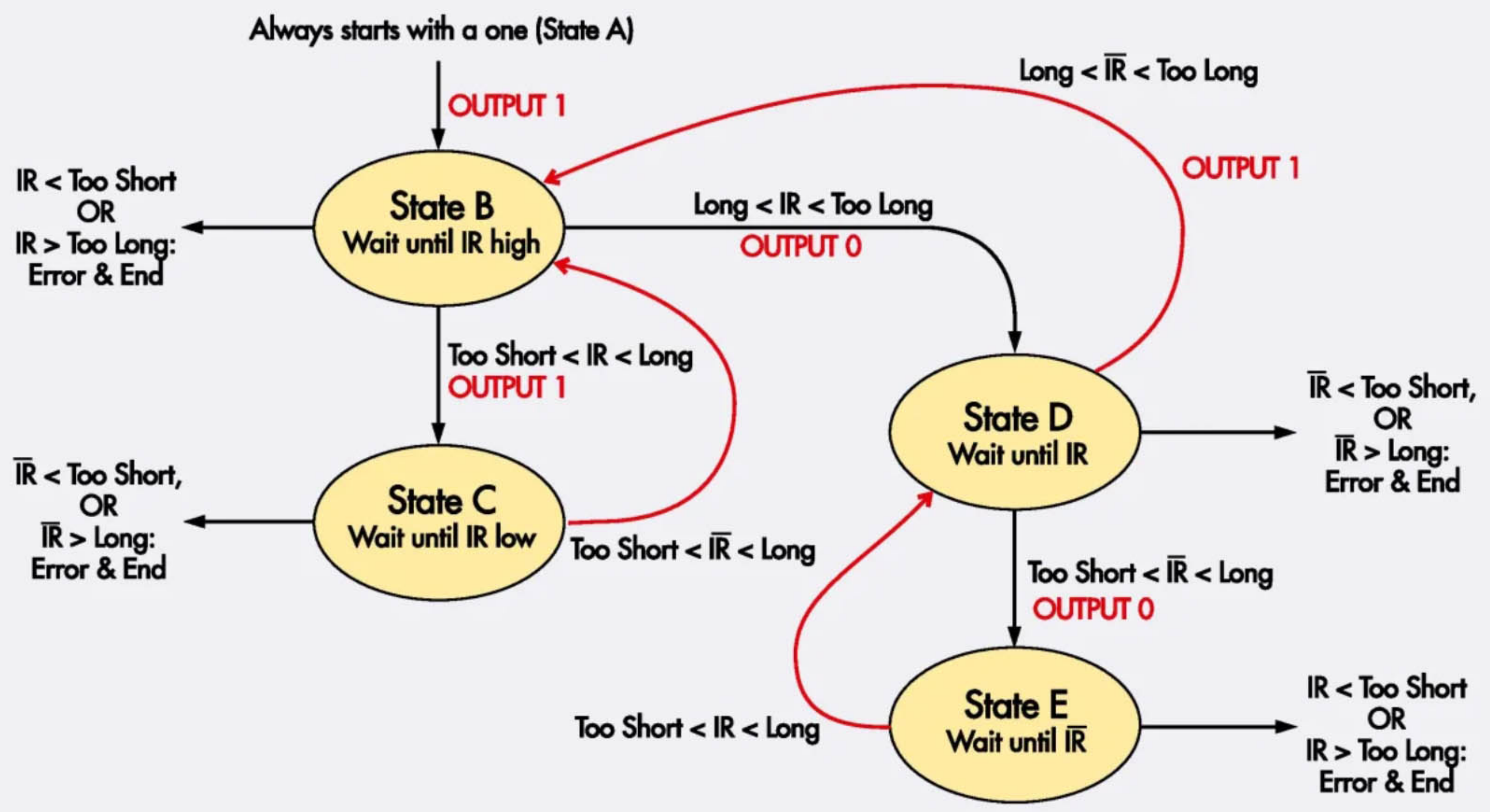

Always starts with a one (State A)
OUTPUT 1
State B
Wait until IR high
State C
Wait until IR low
State D
Wait until IR
State E
Wait until IR̄
IR < Too Short
OR
IR > Too Long:
Error & End
Long < IR̄ < Too Long
OUTPUT 1
Long < IR < Too Long
OUTPUT 0
Too Short < IR < Long
OUTPUT 1
IR̄ < Too Short,
OR
IR̄ > Long:
Error & End
Too Short < IR̄ < Long
IR̄ < Too Short,
OR
IR̄ > Long:
Error & End
Too Short < IR̄ < Long
OUTPUT 0
Too Short < IR < Long
IR < Too Short
OR
IR > Too Long:
Error & End

Fig.5: the IR decoder state machine built into the software. This demonstrates how complex logic can be decomposed into a (relatively) simple flow chart and then implemented in logic or software. Writing software can become difficult without breaking the logic down like this.

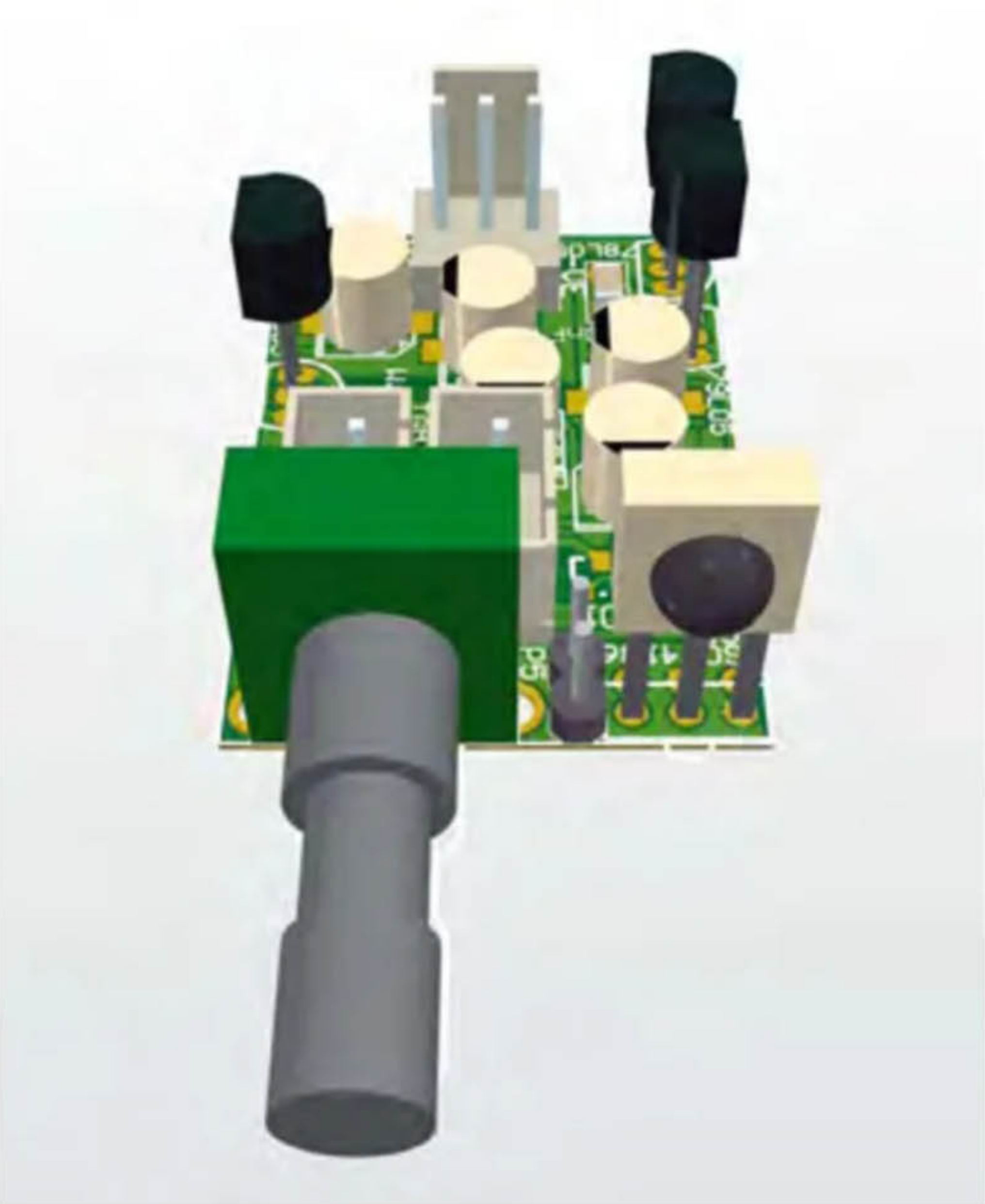


Fig.6: this is the 3D rendering we produced using Altium to verify that everything was going to fit. The final result looks remarkably similar.

checks and even get a rendering of what it will look like once assembled. We can spin it around to ensure there are no component collisions (and Altium can warn us if there are).

Construction

First, you need to choose which board you want to build. The SMD version is suitable for relative beginners as it has a handful of surface mount parts but no really fine pitch components. That said, if you have room for the full-size board, it might save you some squinting to build that version. This especially applies to those of us with a few extra 'miles on the clock'.

SMD version

The SMD version is built on a double-sided PCB coded 01101231 that measures 25.5 × 36.5mm abd which is availabel from th *PE PCB Service*. It is shown with the components placed in Fig.7. Components are mounted on both sides to keep the final result compact. You might want to use a small vice or some Blu-Tack to stop the PCB from slipping around on the bench while you work on it.

Start by soldering the 10kΩ resistor on the back of the board. Next, fit the 100nF capacitors. Four are on the board's back, and two are on the front.

Next, fit the PGA2311 IC (or similar) and the PIC16F15124 microcontroller. In both cases, ensure you have identified pin 1 and oriented it as shown in Fig.7 and the PCB silkscreen before tacking one pin. Then check the alignment of the other pins before soldering them. If they are off, remelt the first solder joint and gently nudge the IC into position.

Adding a bit of flux paste along the rows of pins before applying solder is recommended, as it makes the solder flow much better, to form good joints. With flux paste on the pins, you just need to load a little solder on your iron and then touch it to the junction of the pin and pad, and it should flow onto them and form a good joint.

With practice, you can even drag the iron down the pins to solder them in rapid succession.

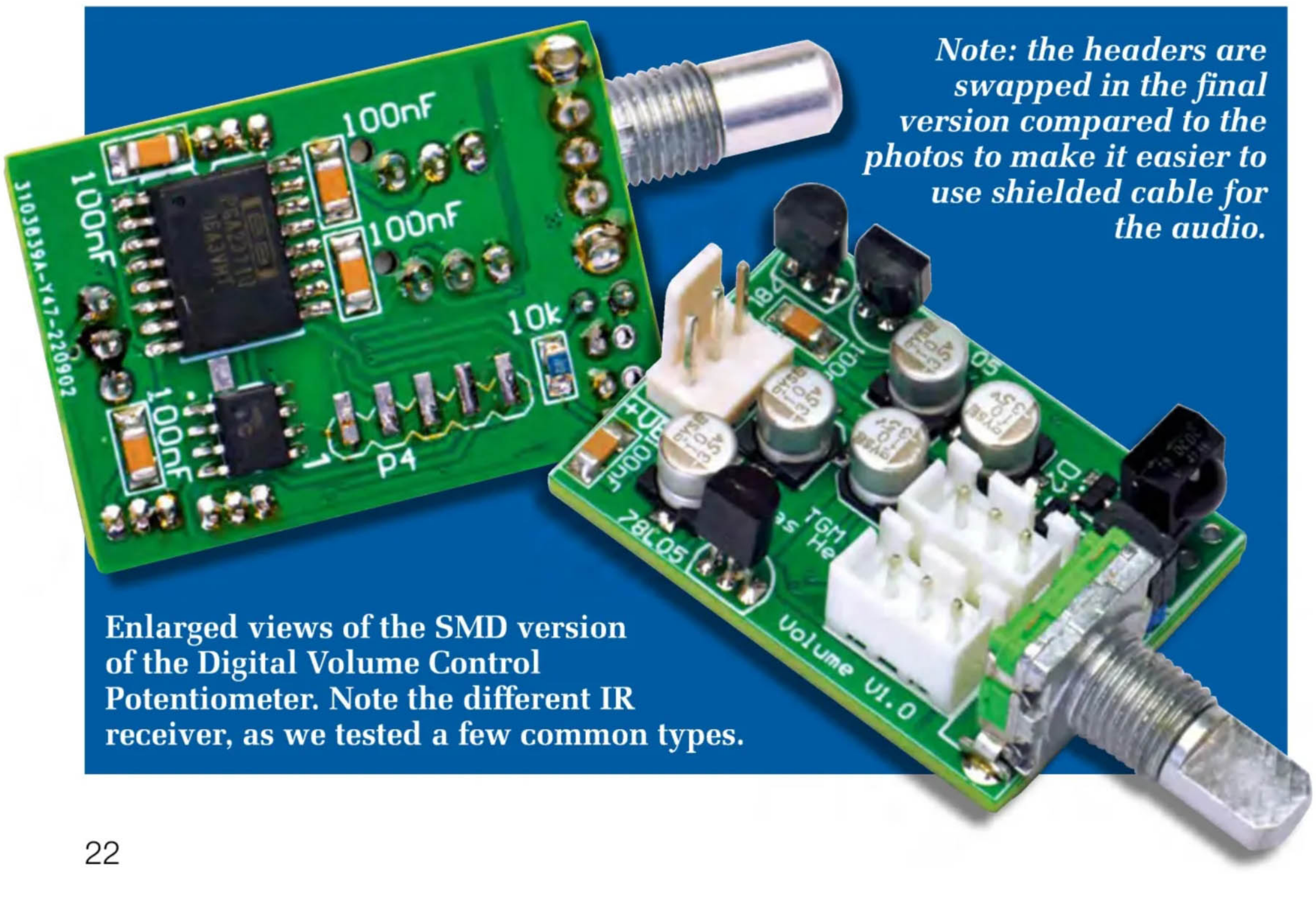
After soldering, check carefully to ensure all the joints are good and no pins are bridged to adjacent pins with solder. If they are, add a bit more flux paste and then apply some solder wick to suck up the excess solder and clear the bridge.

Now flip the board and solder the two dual BAT54S schottky diodes. These are SOT-23 package devices and the smallest parts you will need to deal with, but luckily, the pins are relatively widely spaced. Once you have these on the board, it is all downhill from there.

Next, fit all five 10µF 35V SMD electrolytic capacitors (or, even better, 10µF 35V/50V SMD ceramics). If using electrolytics, orient them as shown; the base has a chamfer at the positive end. You can use a small amount of solder to wet one pad and tack the capacitor lead to hold it in place before properly soldering both pins.

Leave that fine tip on your soldering iron, as while the remaining parts are through-hole types, many of these parts use smaller pads to fit the tracks onto the PCB. Solder in the three voltage regulators next. Be careful to get the 78(L)05 and 79(L)05 devices in the right spots.

Next, mount the power and output connectors. We have chosen different types for these to make it less likely that the power will be inadvertently

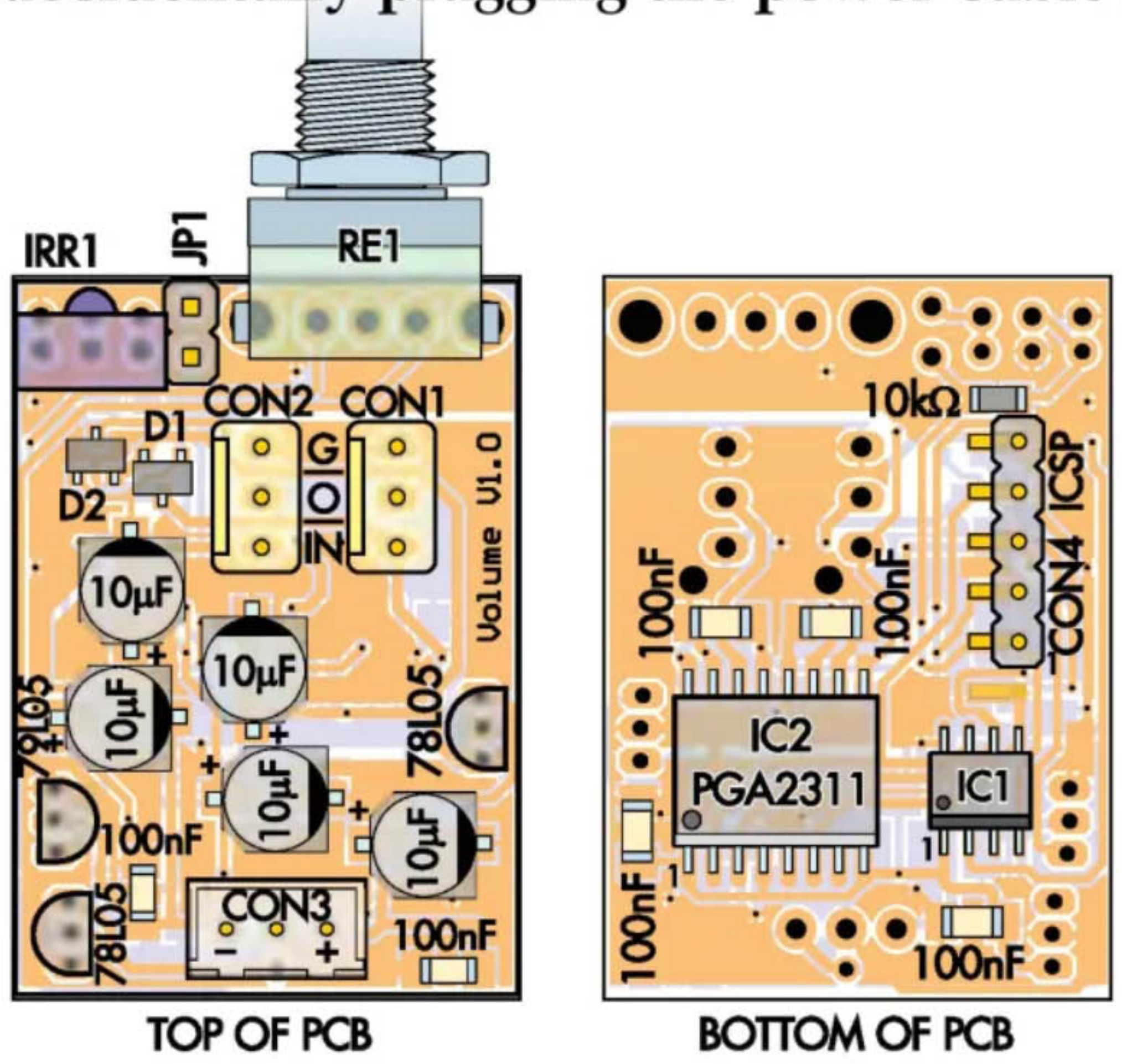


Note: the headers are swapped in the final version compared to the photos to make it easier to use shielded cable for the audio.

Enlarged views of the SMD version of the Digital Volume Control Potentiometer. Note the different IR receiver, as we tested a few common types.

100nF
100nF
100nF
100nF
10k
P4
78L05
Volume V1.0

Fig.7: the SMD version is very compact but is identical in performance and function to the larger through-hole version. If using 10µF ceramic capacitors instead of electrolytic (which we would recommend), they will fit on the same pads but are not polarised. You can use the same type of connector for CON3 as CON1 and CON2 but then there is a risk of accidentally plugging the power cable into the wrong header and doing damage.


IRR1
JP1
RE1
D1
D2
CON2
CON1
G
O
IN
Volume V1.0
10µF
10µF
10µF
10µF
10µF
79L05
78L05
78L05
100nF
100nF
CON3
10kΩ
ICSP
CON4
100nF
100nF
IC2
PGA2311
IC1
100nF
100nF
TOP OF PCB
BOTTOM OF PCB

Choosing an infrared remote control

We tested several remotes during development, including the Altronics A1012A. We programmed this for TV codes 0088, 0154, 0169 and others and AUX codes 0734, 0846, 0727 and others. We also tested a 'One For All' remote and found it worked with TV code 0556 and RCVR/AMP code 1269.

The easiest way to set this up for your remote is to plug the IR activity LED into the program port and watch for the LED lighting when you press buttons on the remote. Flashing indicates that valid IR codes are being received. It's then just a matter of trying different codes (starting with Philips TVs) until you find one that works. You only need the volume up/down and mute button codes to be correct.

plugged into the audio connector. It is possible to solder wires directly to the PCB, but connectors provide a more professional finish and definitely make for easier assembly and maintenance.

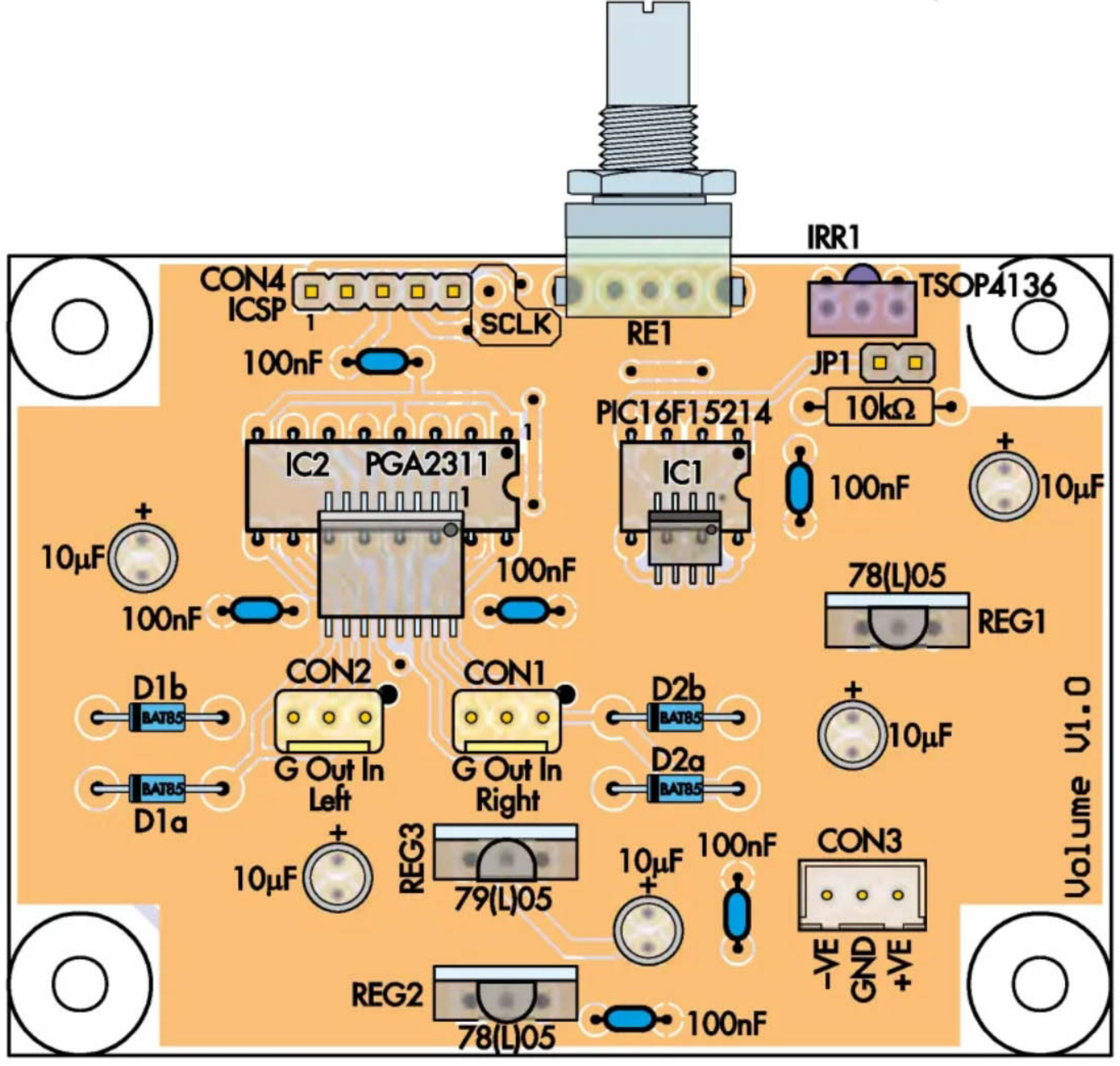

IRR1
TSOP4136
CON4
ICSP
SCLK
RE1
JP1
10kΩ
100nF
PIC16F15214
IC2
PGA2311
IC1
100nF
10µF
10µF
100nF
100nF
78(L)05
REG1
D1b
D1a
CON2
G Out In
Left
CON1
G Out In
Right
D2b
D2a
10µF
Volume V1.0
10µF
REG3
79(L)05
10µF
100nF
CON3
–VE
GND
+VE
REG2
78(L)05
100nF

Fig.8: the through-hole PCB is electrically identical to the SMD version but somewhat larger. For both IC1 and IC2, you can fit a part in a DIP (through-hole) or SOIC SMD package. Be careful which way around you install the regulators and ICs, and note the extra pad next to CON4 so that multiple units can be 'ganged up' for four or more channels.

A two-pin header is used as a jumper to isolate the IR receiver in case IC1 needs to be reprogrammed. If you need to program your PIC, install this header but do not fit the jumper until after the PIC is programmed. If you are using a pre-programmed PIC, you can insert the jumper before or immediately after soldering it.

The final part to install is the IR receiver. There are many similar types on the market, but they have annoying pinout differences. Some have the + and – power supply pins swapped! **Check the ones you buy carefully; the specified TSOP4136 devices have GND on the middle pin and fit the inner set of holes on the PCB. TSOP2136 devices have GND on an outer pin, matching the pads nearest the PCB edge.**

Through-hole version

The through-hole version is built on a double-sided PCB that's coded 01101232 and measures 78.5 × 57mm (also from *PE PCB Service*). The parts layout on this board is shown in Fig.8.

This board allows the use of all through-hole parts or, alternatively, you can use the surface-mounting versions of the PIC microcontroller and/or PGA2311 IC. This makes sourcing parts easier. All the remaining through-hole parts are very common, so we do not envisage any difficulties in sourcing them.

The assembly order is essentially the same as for the SMD version, listed above, with a few minor differences besides the different component packages. The main one is that the two dual SMD diodes are replaced with four individual leaded diodes. Also note that the through-hole electrolytics have their positive sides indicated using longer leads, which go towards the + symbols on the board.

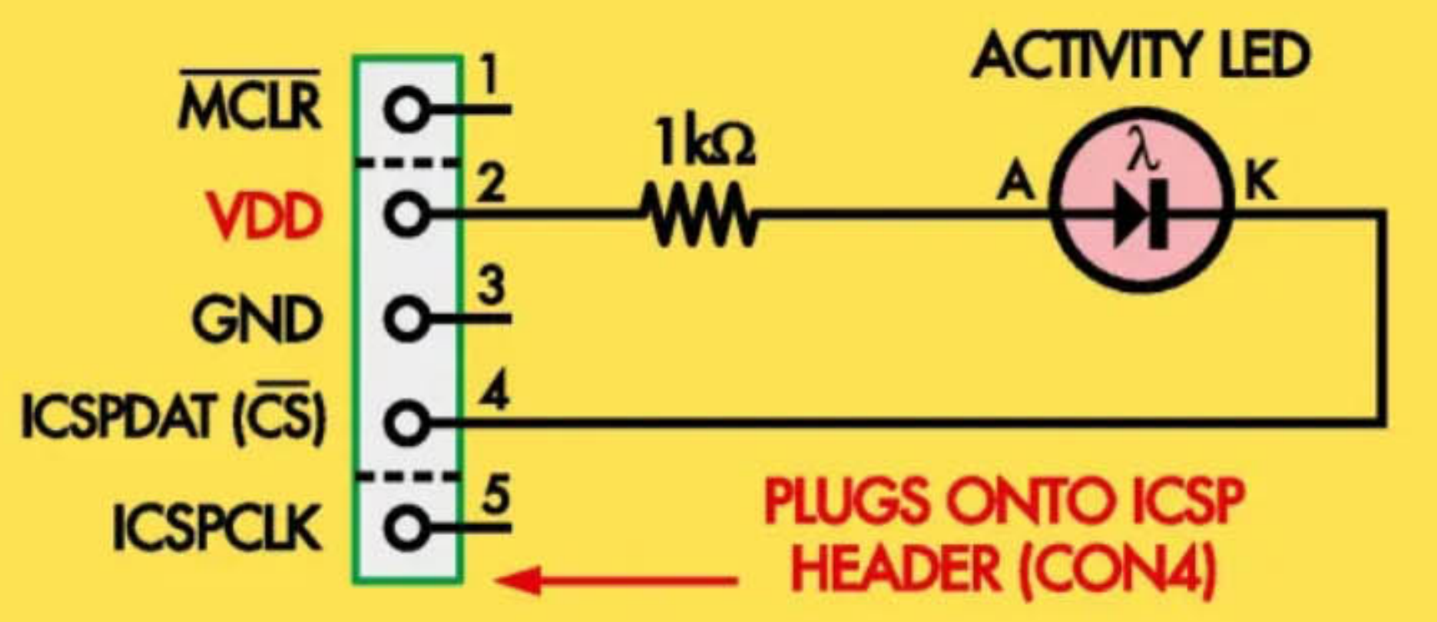
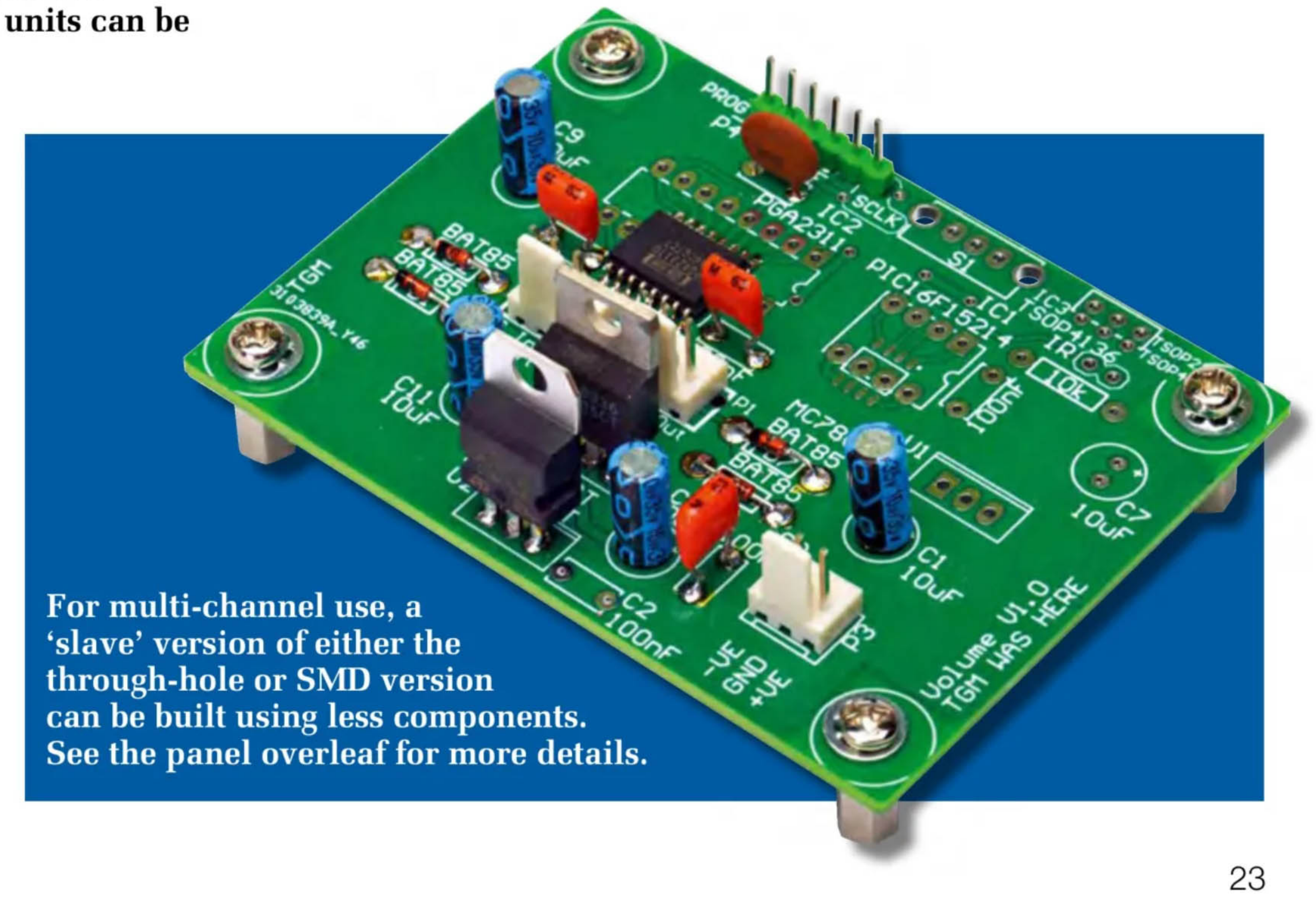

MCLR
VDD
GND
ICSPDAT (CS)
ICSPCLK
1
2
3
4
5
1kΩ
ACTIVITY LED
A
K
λ
PLUGS ONTO ICSP HEADER (CON4)

Fig.9: this circuit shows how to add an IR activity LED. We piggyback off the CS line for the PG2311 IC, which itself re-purposes the in-circuit serial programming data line. It can be a 3-, 4- or 5-pin header as long as it's plugged into CON4 so the correct connections are made; you can adjust the resistor value to suit the LED used.



For multi-channel use, a 'slave' version of either the through-hole or SMD version can be built using less components. See the panel overleaf for more details.

For the regulators, you might as well use the same 78L05 and 79L05 devices as used on the SMD version; orient them as per the smaller semi-cylindrical footprints shown in Fig.8. However, you can also use the 7805/7905 or equivalent TO-220 regulators if you happen to have them on hand; the required orientation of those devices is also shown in Fig.8.

Otherwise, follow the same order of assembly as the SMD version, referring to the section above. After that, you can install the four 'feet' comprising tapped spacers held into the corner mounting holes with machine screws. These are not only handy during testing; you can use them to mount the more hefty through-hole board to the chassis later.

Activity LED

An activity LED is a useful thing to have; one that flashes at power-up, when valid infrared commands are received and when the encoder is rotated. To provide for this, the firmware stretches the length of the $\overline{\text{CS}}$ 'chip select' signal to the PGA2311 IC. By connecting our LED and resistor between this line and the 5V rail, it will light up whenever commands are sent to that IC.

This is a bit cheeky, as we are using the chip select line for two purposes: while the $\overline{\text{CS}}$ line is low to enable the PGA2311's digital interface, it also drives current through the activity LED to light it. To make the flash visible, we need to extend these pulses from what is required (just a few microseconds) to tens of milliseconds.

The wiring for the optional activity LED is shown in Fig.9. It is done by soldering the light-duty figure-up cable to two pins on a female header with three to five pins. You can cut this from a longer header strip. It then plugs onto CON4 and allows you to mount the LED in a visible location, eg, on the front panel of your amplifier using a bezel. Try to keep this lead to a modest length (~10cm), as it helps to prevent noise getting on the $\overline{\text{CS}}$ line.

Programming IC1

If yo are using a blank microcontroller, you will have to program it in-circuit for the SMD version (unless you have an SOIC programming socket). With the through-hole version, you can program it in-circuit or off-board before fitting it (or even afterwards if you're using an IC socket).

For programming it in-circuit, remove JP1 and plug a programmer like a PICkit 4 or Snap programmer into CON4 with its pin 1 in the correct position. With the PICkit 4, you can get the programmer to deliver power during programming. For the Snap programmer, it's probably easiest to apply 12V DC between the +VE and GND pins of power header CON3 during programming.

Parts List – Digital Volume Control 'Potentiometer'

1 universal remote control **[Altronics A1012A]**
1 rotary encoder (RE1) **[Altronics S3350 or EN11-VNM1BF15 (Mouser)]**
2 3-pin vertical polarised headers, 2.54mm pitch (CON1, CON2) **[Altronics P5493]**
2 3-way polarised header plugs with pins (for audio signals via CON1, CON2) **[Altronics P5473 + 3 x P5470A]**
1 3-pin JST style header, 2.54mm pitch (CON3) **[Altronics P5743]**
1 3-pin JST style plug, 2.54mm pitch (for power via CON3) **[2 x Altronics P5743 + 6 x Altronics P5750]**
1 2-pin vertical header, 2.54mm pitch, plus jumper shunt (JP1)
1 TSOP4136 or similar IR receiver, SIL-3 (IRR1) **[Altronics Z1611A, Jaycar ZD1953, Mouser 782-TSOP4136]**

Additional components for the SMD version

1 double-sided PCB coded 01101231, 25.5 × 36.5mm from the *PE PCB Service*
1 6-pin SMD vertical header, 2.54mm pitch (CON4) (**optional**; for ICSP, activity LED and/or multi-channel use) **[Altronics P5435]** ★
1 PIC16F15214-I/SN 8-bit microcontroller programmed with 0110123A.HEX, SOIC-8 (IC1)
1 PGA2311, PGA2310, PGA2320 or CS3310 digital volume control IC, wide SOIC-16 (IC2)
2 78L05 +5V 100mA linear regulators, TO-92 (REG1, REG2)
1 79L05 -5V 100mA linear regulator, TO-92 (REG3)
2 BAT54S 25V 200mA dual series SMD schottky diodes, SOT-23 (D1, D2) **[Altronics Y0075]**
5 10µF 35V SMD electrolytic capacitors, 5.3×5.3mm **[Altronics R9442]** ***OR***
5 10µF 35V/50V SMD ceramic capacitors, X5R or X7R, M3216/1206 size
6 100nF 50V X7R SMD ceramic capacitors, M3216 size **[Altronics R9935]**
1 10kΩ SMD resistor, M2012/0805 size **[Altronics R1148]**

Additional components for the through-hole version

1 double-sided PCB coded 01101232, 78.5 × 57mm from the *PE PCB Service*
1 6-pin vertical header, 2.54mm pitch (CON4) (**optional**; for ICSP, activity LED and/or multi-channel use)
1 8-pin DIL IC socket (**optional**; for IC1 if DIP version used)
1 PIC16F15214 8-bit microcontroller programmed with 0110123A.HEX, DIP-8 or SOIC-8 (IC1)
1 PGA2311, PGA2310, PGA2320 or CS3310 digital volume control IC, DIP-16 or wide SOIC-16 (IC2)
2 78L05 or 7805 +5V 100mA/1A linear regulators, TO-92 or TO-220 (REG1, REG2)
1 79L05 or 7905 -5V 100mA/1A linear regulator, TO-92 or TO-220 (REG3)
4 BAT85 30V 200mA schottky diodes (D1a/b, D2a/b) **[Altronics Z0044]**
5 10µF 50V low-ESR radial electrolytic capacitors, 5mm diameter **[Altronics R6067]**
6 100nF 50V X7R multi-layer ceramic capacitors, 5mm pitch **[Altronics R2931]**
1 10kΩ ¼W resistor
4 M3-tapped spacers (for mounting PCB)
8 M3 × 6mm panhead machine screws (for mounting PCB)
4 M3 shakeproof washers (for mounting PCB)

Optional parts for activity LED (suits either version)

1 LED with bezel and series current-limiting resistor
1 length of light-duty figure-8 wire, to suit installation
1 3-pin, 4-pin or 5-pin female header, 2.54mm pitch

★ *Most SMD headers, including Altronics Cat P5435, have the pins staggered on either side of the header. The PCB requires the pins to all be on one side. This can generally be achieved by snapping or cutting off a 5-pin or 6-pin length of the header and rotating the even-numbered pins by 180°.*

Using MPLAB IPE, select the correct device (PIC16F15214), load the HEX file (available for download from the March 2024 page of the PE website: **https://bit.ly/pe-downloads**), enable power from the programmer if necessary, then connect to the chip and press the program button. It should only take a couple of seconds to load the firmware, and you will see a success message (or an error message if something goes wrong).

Remember to re-fit the shorting block to JP1 after disconnecting the programmer.

Changing remote control code

The software can decode RC5 signals with any valid TV or 'Receiver' address. The software defaults to the TV on first power-up, and if you do not need to change this, there is nothing to do.

If you have another Philips TV remote in the room and need to use an alternative code, here is how to set the *Digital Pot* to use the Philips Receiver codes.

To set the remote using a TV code:

1. Remove power from the *Digital Pot*.
2. Short pins 3 and 5 of CON4.
3. Apply power to the *Digital Pot*.
4. Wait a couple of seconds
5. Remove power from the *Digital Pot*.
6. Remove the short between pins 3 and 5 of CON4.

To set it to accept a Philips Receiver remote control code, just go through the steps listed above but instead, put the jumper between pins 3 and 4 of CON4.

This procedure is the same for the through-hole or SMD versions, but if you haven't fitted CON4, you will need to do so. Note that pin 1 of this header on the SMD board is nearest to the PIC microcontroller.

Troubleshooting

If it isn't working as expected, check the following:

1. Is there 5V DC ±0.25V on the +5VD (IC2 pins 1, 4 and 8) and +5VA (IC2 pin 12) rails?
   - If not, check for any parts getting hot.
   - Verify that you are providing a minimum of 7V DC to the PCB positive input.
   - Do you have the right parts for REG1 and REG2, in the correct orientations?
2. Are IC1 and IC2 soldered properly? Take a close-up photo if your phone has this function; it is surprising how zoomed-in you can get with some phones.
3. Is there activity on the encoder lines (pins 2 and 3 of IC1)?
   - If you have a 'scope, probe pins 2 and 3 of IC1 and see if they are at more than 3V, pulsing low as you rotate the encoder. If not, check that you have used a suitable encoder – there are a bewildering variety of rotary encoders; the recommended Altronics and

Ganging up multiple boards for more than two channels

One really useful feature of this Digital Pot design is that it is easy to run one as a master and one or more as slaves. This allows one volume control or remote to set the level on four, six or more channels.

This is great if you are making a home theatre system and want to use your own amplifiers. It is also handy if you want to control multiple channel levels in a multi-room system or need to adjust the level of multiple channels from one control.

You can use either the through-hole or SMD versions to do this. The master is fitted with all the parts, while the slave(s) have the microcontroller, rotary encoder, infrared receiver, REG1 and associated parts left off.

You need to have the programming header fitted to all the boards, and importantly, it must have six pins rather than five. The extra pin goes into or onto a pad labelled SCLK, right at the end of the programming header, allowing you to extend it by an extra pin.

You then run a cable to join all the six-pin programming headers in parallel. That's all you have to do! But remember to leave off the PIC microcontroller, REG1, IR receiver and encoder on each slave board. Otherwise, they will interfere with the master.

To make a six-way ribbon cable that can join the boards, you can use two Altronics P5380 header sockets (or cut two 6-pin sections from a P5390 or similar strip). Wire pins 1-1 through 6-6 together using ribbon cable and insulate the soldered connections using 3mm diameter heatshrink tubing. Mark pin 1 at each end so you don't accidentally swap them! That could cause damage to one or more boards.

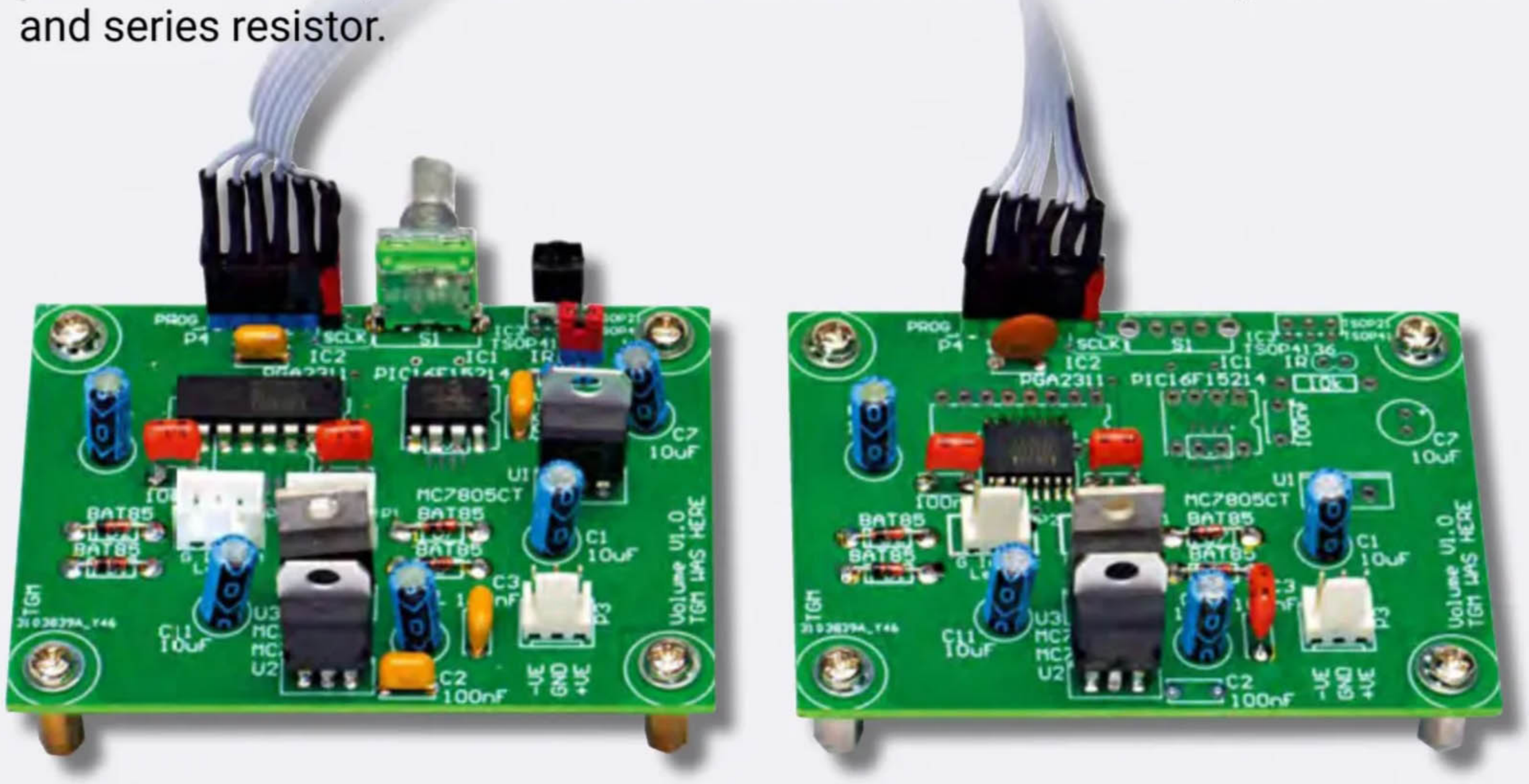
We tested this using 200mm of ribbon cable with no problems. This interface does not have fast data, so we expect you can stretch this a little if needed.

You could also use a 12-way ribbon cable with IDC connectors as long as you were careful to plug the six-pin header into the same subset of the 12 pins on each connector. That might be easier since crimping IDC headers onto a ribbon cable only takes a few seconds with the right tool.

Note that you still need to provide power to all boards (master and slave) since only the 5V digital power rail is carried on the connecting cable. They will generate independent split analogue supplies.

With the power connections made and the programming headers joined, you just need to connect the audio inputs and outputs to your various channels, ensure JP1 is fitted only on the master board, then power it up and go through the regular testing procedure.

Note that the SCLK pin is at opposite ends of programming header CON4 on the SMD and through-hole boards, so you can't mix the different board types (at least not without re-routing that signal between them). Also note that if you want to connect an IR activity LED to multiple ganged Digital Pots, you will need to split out those two wires from the harness to go to the LED and series resistor.



This simple cable allows the master and slave Digital Pot boards to be ganged up to make a four-channel volume control. It can be extended to three boards for six channels and so on.

Mouser parts have been tested to work.

4 Power up the board and monitor the $\overline{CS}$ line with an oscilloscope (IC1 pin 7). On power-up, the micro writes data to the PGA2311 for a couple of seconds to ramp the volume.

- If this signal is present, the PIC is running and programmed correctly.
- If you don't have an oscilloscope, watch the LED very closely in a darkened room on power-up. After power is applied, you should see the LED light dimly for a second or two.
- If there is no activity on the $\overline{CS}$ line, go back and check power and check that your micro is programmed. You can also monitor the SDI and SCLK lines (IC1 pins 5 and 6) for activity. These should be active for the first second or so after power-up and when the encoder is rotated.

5 If the IR remote does not work:

- Have you installed the shunt on JP1?
- Have you put the TSOP4136 in the right location?
- Check the signal on JP1 or pin 2 of the TSOP4136 with an oscilloscope; there should be clear activity when the remote buttons are pressed.
- Have you programmed the remote with the right code? If using a universal remote, you will likely need to try a few of the configuration numbers for your remote to get it working. Install the activity LED and watch for the LED to flash; this will tell you that the remote is transmitting codes that work.
- Note that if you need to program your PIC on the board, you will need to remove the shunt from JP1. Many TSOP4136 devices otherwise stop the PIC from being programmed. Remember to reinstall the shunt after programming.

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Are AliExpress PGA2311 ICs any good?

We bought some PGA2311 chips from AliExpress (www.aliexpress.com/item/1005003043805799.html). We built and measured the performance of a Digital Pot using one of these, and it worked just fine – see Fig.10. At £11.63 for five ICs, this is a rather attractive option!

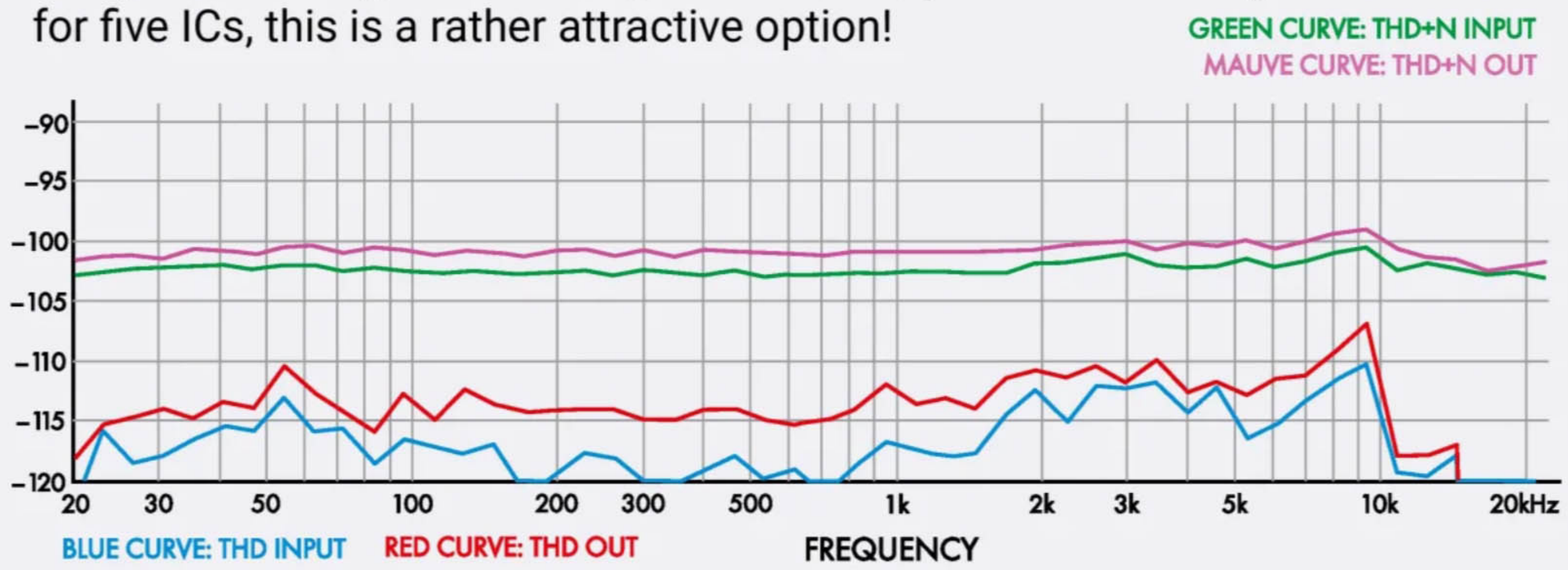

Fig.10: despite costing just over $4 each, the board built with the PGA2311UAs we got from AliExpress gave extremely low THD readings, just like the boards built with chips from more reputable vendors.

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Teach-In 9 – Get Testing!

This series of articles provides a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. It provides hints and tips on using, and – just as importantly – interpreting the results that you get. The series deals with familiar test gear as well as equipment designed for more specialised applications.

The articles have been designed to have the broadest possible appeal and are applicable to all branches of electronics. The series crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone!

Each part includes a simple but useful practical test gear project that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible, and most of them can be built for less than £10 (including components, enclosure and circuit board).

PLUS! You will receive the software for the *PIC n' Mix* series of articles and the full *Teach-In 2* book – *Using PIC Microcontrollers – A practical introduction* – in PDF format. Also included are Microchip's *MPLAB ICD 4 In-Circuit Debugger User's Guide*; *MPLAB PICkit 4 In-Circuit Debugger Quick Start Guide*; and *MPLAB PICkit4 Debugger User's Guide.*

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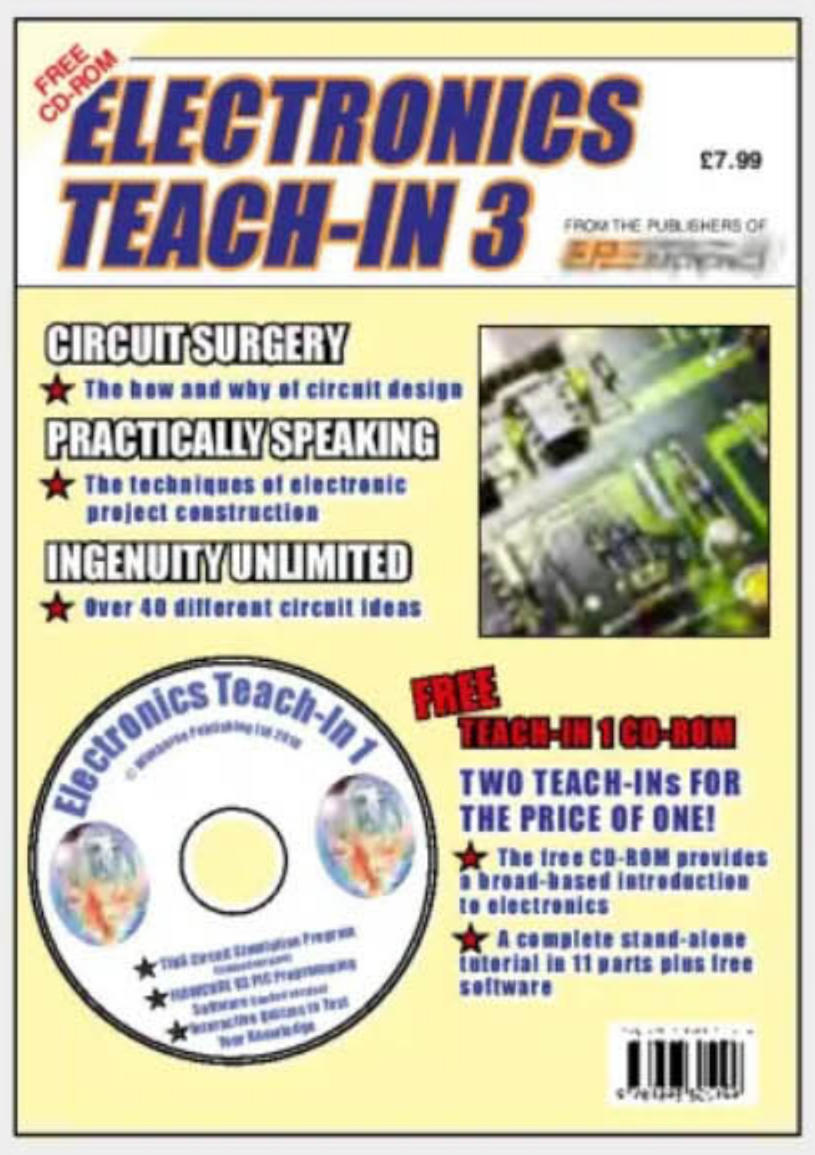

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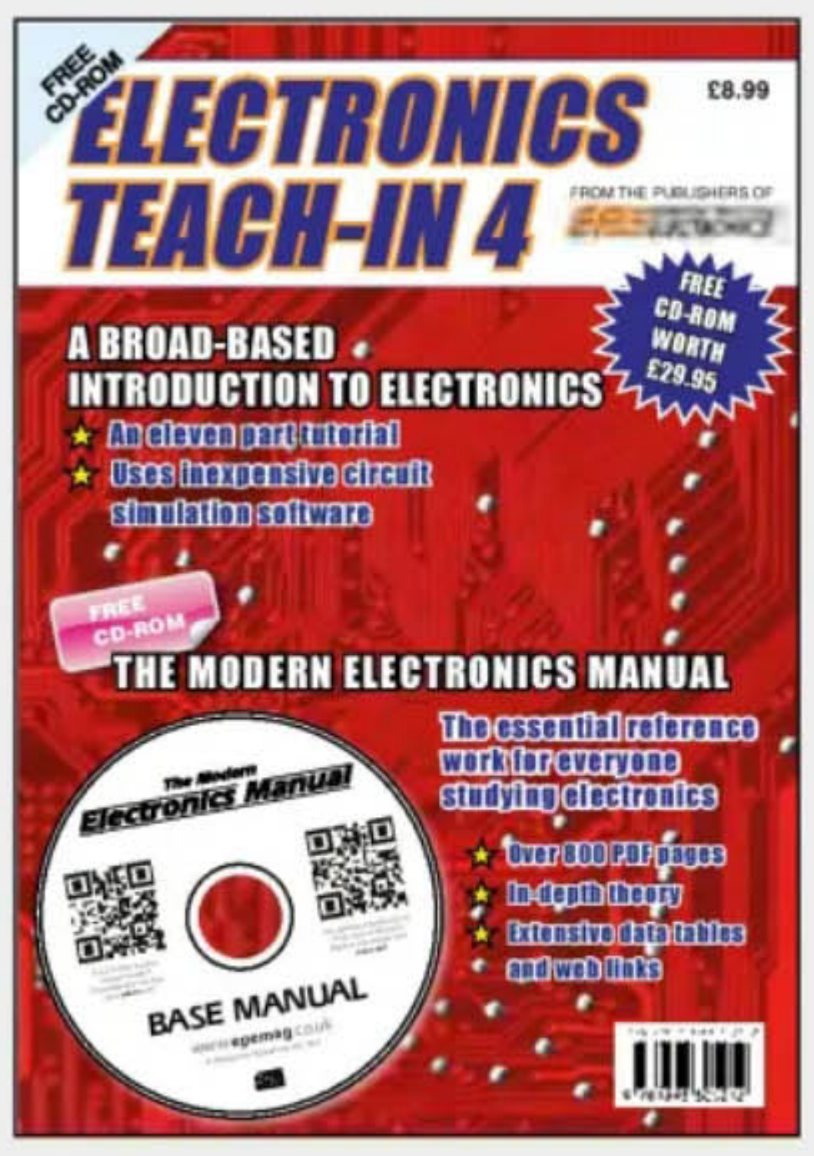
Mike & Richard Tooley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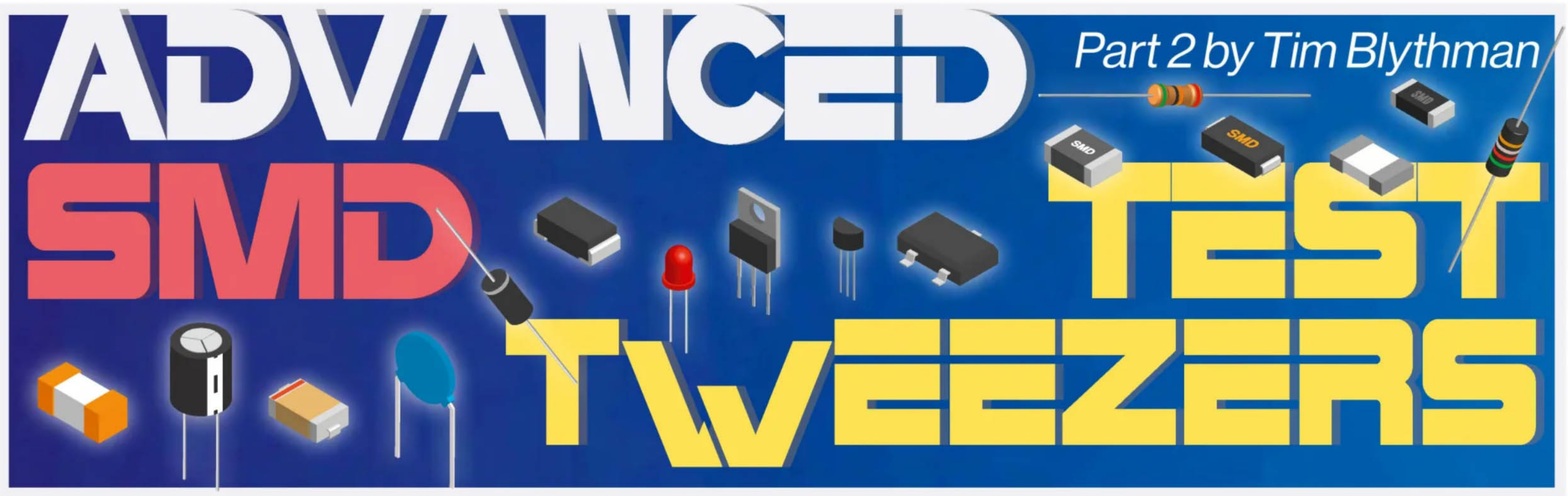
ADVANCED SMD TEST TWEEZERS

Part 2 by Tim Blythman



This new design, introduced last month, adds many features to the SMD Test Tweezers concept. No longer only for testing passive components, the new Tweezers can also act as a voltmeter, logic probe, basic oscilloscope, square wave generator and serial protocol analyser. This final article has all the construction and usage details.

The Advanced Test Tweezers circuit is simple and the PCB compact. The new functions are provided by the substantially larger firmware hosted in a 16-bit PIC24 rather than an 8-bit PIC12 or PIC16. That's due to the PIC's hugely increased flash memory size, up from 7kiB to 256kiB, for only a couple of dollars more!

This has allowed us to fit so many new modes, and enhance the existing ones, that a substantial part of this article will explain how to use them all. But before we get to that, we need to assemble the *Tweezers*. Gather the parts yourself and program a blank PIC using software downloaded from the Fenruary 2024 page of the *PE* website – see: **https://bit.ly/pe-downloads** – or you can buy a PIC already programmed when you buy the PCBs from the *PE PCB Service*.

Construction

Like the earlier *Tweezers* variants, we're mainly using surface-mounting parts to keep it compact. The main change from the earlier versions is that the 28-pin micro has more closely-spaced pins than the 8-pin micros used before, but some passives are slightly smaller too. So you will need tweezers, flux paste, solder-wicking braid and a magnifier to complete this build.

Use solder fume extraction or work outside if you don't have one. Refer to Figs.5 and 6 (the PCB overlays) and photos as you go, which show where the components are mounted.

The design uses an SSOP-28 package microcontroller and M2012/0805 passive components, so the pin spacings are a bit tighter than the SOIC-8 and M3216/1206 parts that we used previously. Still, it's eminently doable with patience and a fine-tipped soldering iron (or even a larger tip, if you know how to use it; and remember, flux paste is your friend).

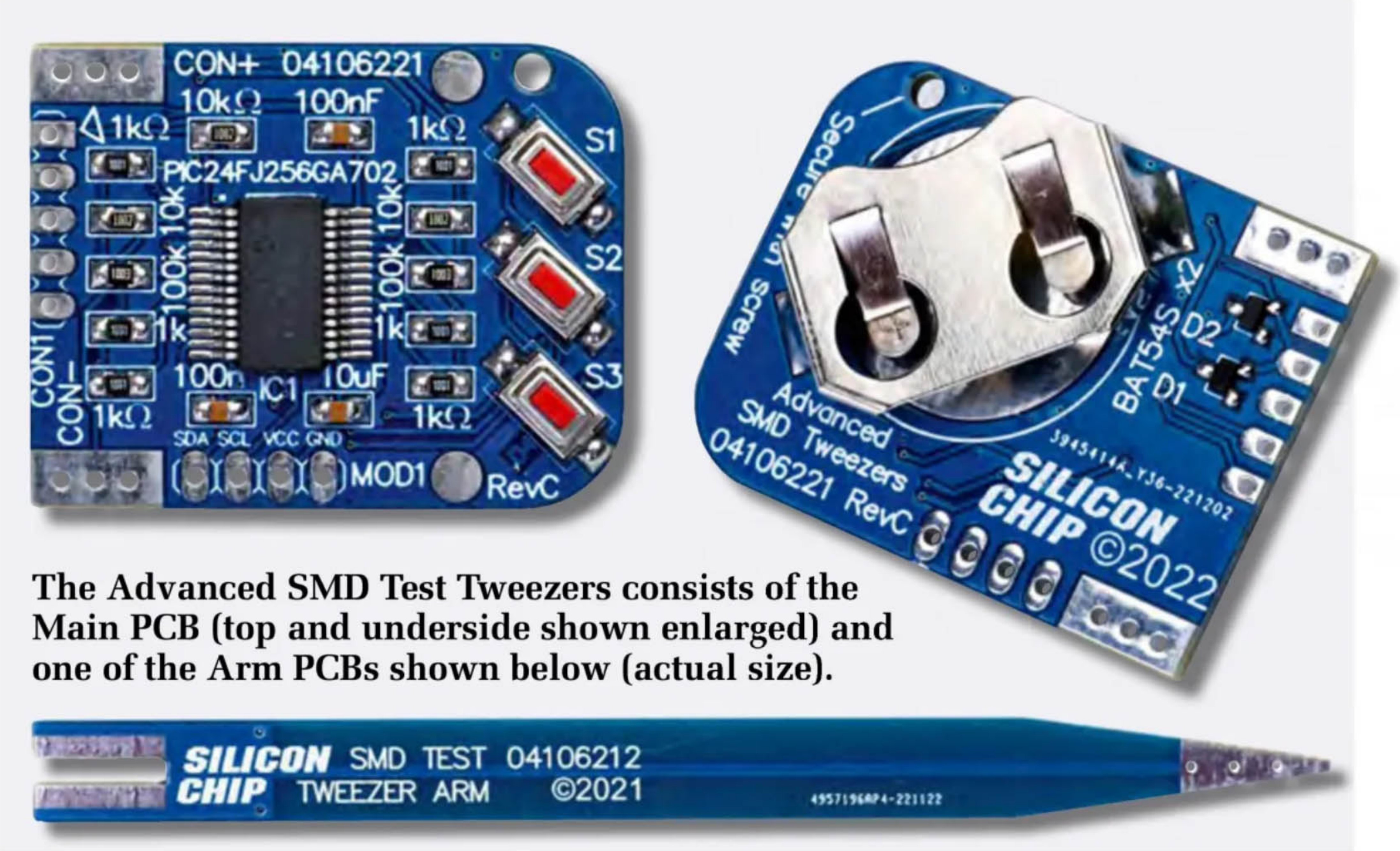
Start by assembling the main PCB and solder the microcontroller first. It's easily the part with the finest pitch pins and is best dealt with if no other components get in the way.

Apply flux to the pads on the PCB, then rest the IC in place, making sure pin 1 is aligned with the dot. Clean the tip of the iron and add some fresh solder, then carefully tack one pin and check with a magnifier that the pins are aligned on their pads and flat against the PCB.

If necessary, adjust its position by remelting the solder and gently nudging it. Your life will be much easier if you get all the pins close to perfectly lined up with the pads now. Then, carefully solder each pin in turn, keeping the iron low on the pads, cleaning the tip and adding solder to it as necessary. You can apply more flux to the pins too. You can also drag-solder them if you know how.

Check that the pins are soldered and that there are no bridges. If there are bridges, add more flux and use some solder wick to draw out the extra solder. Surface tension should leave a small but sufficient amount of solder attached to the pin and pad.

If you haven't previously done any work with parts this small, you might like to clean the excess flux away to make it easier to inspect your work as you go. Even if you're experienced, it's best to clean it up when you're done and use a magnifier to verify that all the solder joints have adhered to the pins and pads, and that there are no hard-to-see bridges.



The Advanced SMD Test Tweezers consists of the Main PCB (top and underside shown enlarged) and one of the Arm PCBs shown below (actual size).

The remaining 14 passive components on the top of the PCB are all M2012/ 0805 size (2 × 1.2mm); none are polarised. The resistors should be marked with codes representing their values, but the capacitors will probably not be. If in doubt, the 10µF part is likely the thicker or larger capacitor.

Apply flux to the pads for all the parts and solder the 10µF capacitor first. Like the IC, tack one lead, check that it is flat and aligned within its pads, then solder the other lead. Apply more flux and touch the iron to the first pad to refresh the joint.

Use the same technique to solder the two 100nF capacitors, then the resistors, in the locations shown in Fig.5.

There are only a few parts on the reverse of the PCB: two diodes and the cell holder, as shown in Fig.6. Solder in the two diodes now. Though small, the SOT-23 parts are pretty easy to work with and should only fit in the correct orientation.

Then solder the cell holder. Make sure that the opening faces the edge of the PCB, as shown in Fig.6 and the photos. Use a generous amount of solder to ensure the connection is mechanically sound.

It's a good idea to clean any flux residue off the PCB now. Doing so at this stage means that the entire PCB can be immersed in a solvent before the switches are fitted, so it won't get into their mechanisms.

Your flux's data sheet should recommend a solvent, but we find that isopropyl alcohol works well in most cases. Allow the PCB to dry thoroughly. The *Advanced Tweezers* can measure relatively high resistances, and traces of flux residue could affect the readings.

Now is a good time to thoroughly inspect the soldering of the smaller surface-mounted parts, as it will be tricky to make any repairs once the OLED has been fitted. Look closely for solder bridges and check that IC1 is in the correct orientation.

Solder the three tactile pushbuttons in place next. That should be easy, as they have relatively large pads. You can carefully wipe away any flux residue left behind with a cotton tip dipped in solvent.

Pre-calibration

The standard 1% resistors used give the *Advanced Tweezers* a useful degree of accuracy. Still, if you have access to an accurate multimeter, you can measure the exact value of the six 'probing' resistors to improve its accuracy. They are marked in red in Fig.5.

These are the 1kΩ, 10kΩ and 100kΩ resistors along the side near the top of IC1. The four lower 1kΩ resistors also affect measurements in the Scope and Meter modes, but we've provided an automatic calibration for them that does not depend on their exact values.

Measure and separately note the exact values of the six resistors. It's much easier to do this now, before the OLED is fitted over the top. A menu will allow these values to be loaded into the *Tweezers* during the calibration stage.

Programming IC1

If you don't have a pre-programmed chip (we sell a programmed micro individually), you will need to program it using a programmer such as a PICkit 3, PICkit 4 or Snap. If you need to provide power to the chip (likely if you are using the Snap), you can temporarily insert a coin cell into the holder.

The ICSP header, CON1, can be soldered in place for programming. However, we find it's sufficient to insert a five-way header pin strip into the PCB pads, so you might like to try that. This way, the header does not get in the way when the arms are fitted. Gentle sideways pressure on the header during programming should keep the pins in contact with the plated holes.

We recommend programming using the free MPLAB X IPE software. Select the correct part (PIC24FJ256GA702) and open the **0410622A.HEX** file. Use the Program button to upload the HEX file to the device.

The only indication that programming was successful will be a message like 'Program/verify complete' in the bottom window of the IPE. If you have fitted a cell, remove it now to complete the assembly.

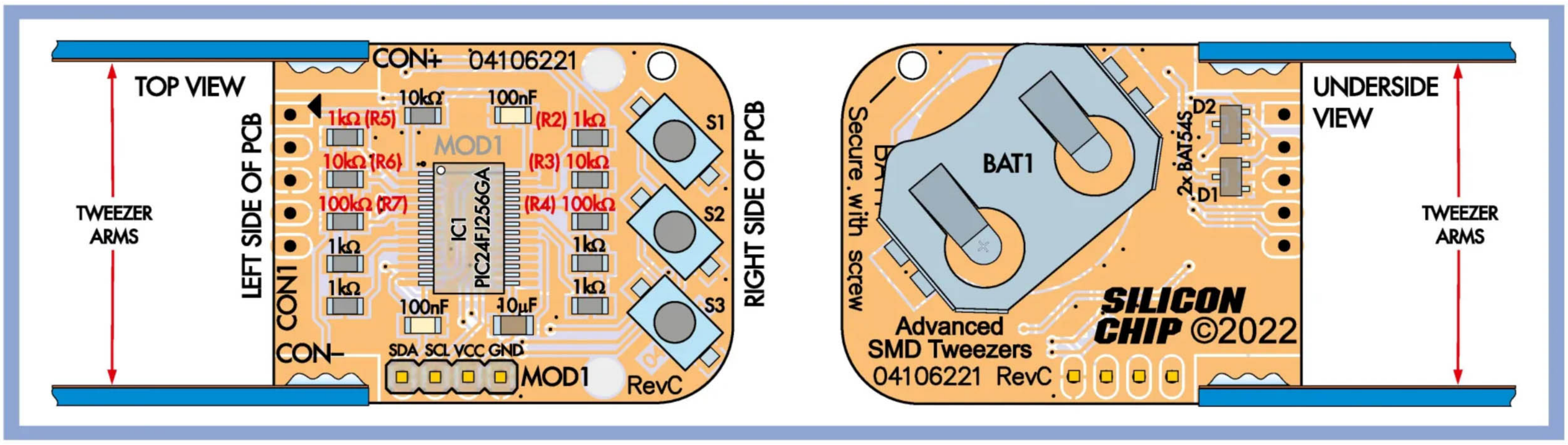
Fitting the arms and tips

The arms must be fitted before the display to ensure that the OLED is spaced clear above the main PCB and clear of the arms. For the tips, we use the same arm design as the *Updated Tweezers* from May 2023, including the gold-plated header pins. Fig.7 shows this arrangement.

The gold-plated header pins are easy to source, and as a bonus, they can also plug directly into prototyping gear like jumper wire sockets and breadboards. Fit the arms to the main PCB, then solder the tips, making it easier to align the tips to be the same length and parallel.

Place the arms as seen in the photos. They connect to the CON+ and CON– pads and should have their copper tracks on the inside of the arms to reduce stray capacitance while they are held.

They should only extend past the CON+ or CON– pads where they leave the PCB. This will keep the arms clear



Figs.5 and 6: remember to measure the resistances of the resistors marked in red and thoroughly check the soldering for bridges before fitting the OLED. It will take a lot of work to get to the top of this PCB (shown at left) after the OLED is fitted. You can use the large pad at top right (light grey) to support the OLED module by soldering a short piece of stiff wire between the two. The cell holder and two dual diodes are on the reverse side of the PCB (shown at right). The diodes should only fit one way, but the cell holder can be reversed. Fit it in the orientation shown so a cell can be inserted from the side near the edge of the PCB. Both overlays are shown enlarged at 150% of actual size.

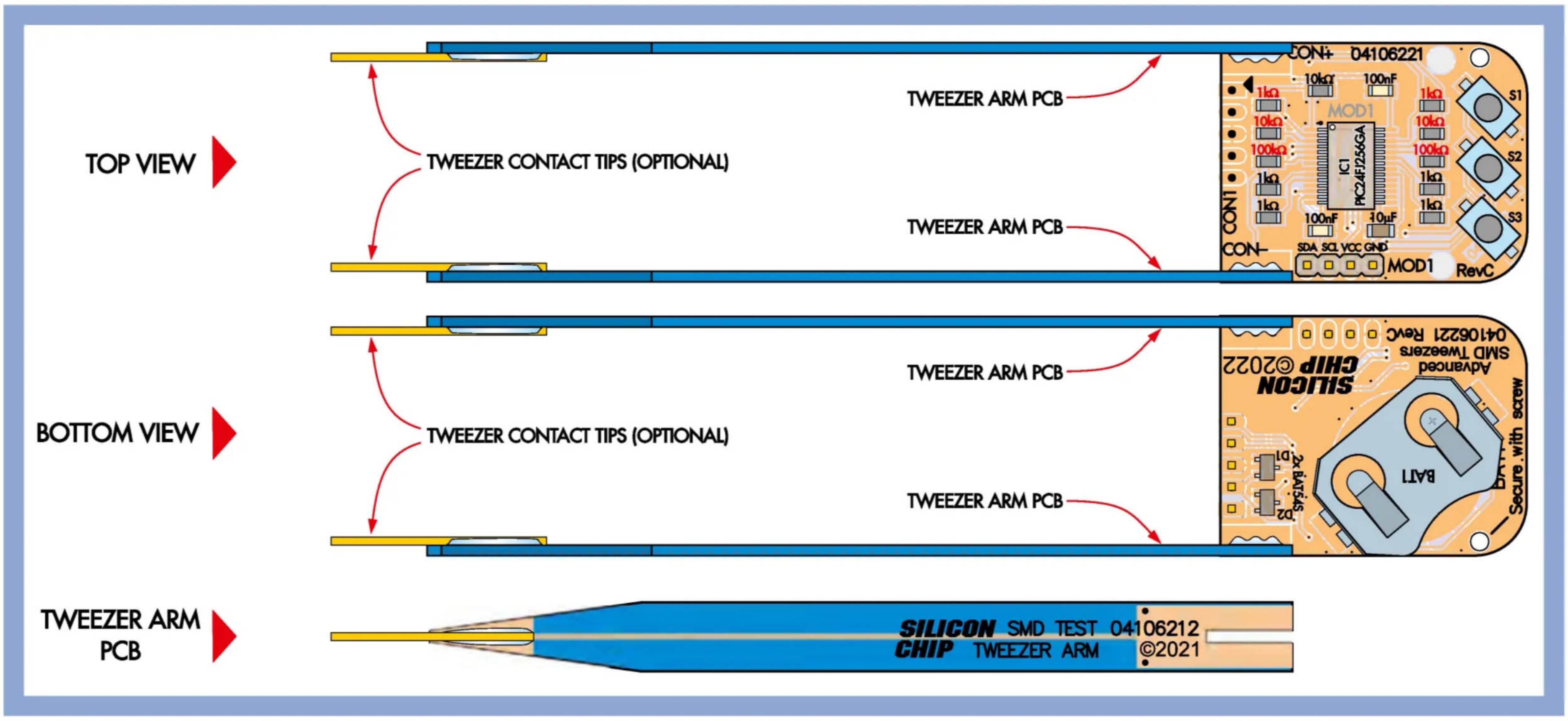


Fig.7: this shows how the two arms attach to the main PCB. It is easier to solder and align the tips to the arms after the arms are fitted to the main PCB. The arms are shown parallel here, but it's better to angle them as shown opposite.

of other connections on the PCB, especially those for the OLED screen.

Angle the arms slightly inward to achieve about 15mm of tip separation when at rest. This will allow the *Advanced Tweezers* to be used with axial leaded components too. You could set them closer if you only use them on surface-mounting parts.

Use a small amount of solder to take the arms and adjust their positions as necessary. Then use a generous amount of solder on both sides of the arms and main PCB to ensure a good mechanical connection between them.

Keep the pin headers side-by-side in their plastic holder until they are soldered, as this will keep them aligned. Use a generous amount of solder and ensure it flows into the holes on the arm PCB, giving more strength.

Test the action of the arms and if necessary, use your iron to melt the solder and adjust them.

OLED installation

The final step is to fit the OLED module, MOD1. If the OLED does not have a header strip fitted, attach that first, ensuring that the pins are perpendicular to its PCB.

The OLED needs to be fitted such that it cannot flex and touch any other part of the *Tweezers*, so space it about 1mm above the arms. You can use Blu-Tack or similar to locate it squarely in place, and tack one lead to confirm. Check that there is clearance all around between the PCB and OLED. Then solder the remaining leads to their PCB pads.

Initial testing

At this stage, the *Tweezers* are complete enough to do a quick functional test. Insert the cell into the holder, and the OLED should light up in Meter mode, with a reading under 1V. Pressing S1 should cause the counter at bottom right to start flashing, and S2 will cause it to stop flashing. Pressing S3 will switch to the next mode (Scope).

If something else happens, your *Tweezers* probably have a problem, so you should remove the cell and check the assembly. If the displayed voltage is wrong, check that the resistors all have the correct values and are in the right locations. Any of the switches not working could point to that switch not being soldered correctly.

Any problem you spot might also be due to a soldering problem with IC1, particularly bridged pins or a solder joint that doesn't contact both the pin and pad.

If all is well, the assembly can be completed after removing the cell. The top-right mounting hole of the OLED is designed to be soldered to the main PCB using a header pin or similar. This will prevent the OLED from flexing at this end and coming into contact with the arms.

You can now apply heatshrink tubing to the arms, taking care not to direct heat towards the OLED screen. Cover as much of the arms as possible from the main PCB to just before the tips.

The back of the *Tweezers* is protected by a small sticker. You could design your own and print it out on a blank sticker or use the one shown in Fig.8 using artwork downloaded from the March 2024 page of the *PE* website: **https://bit.ly/pe-downloads**.

Take care when operating the Advanced Test Tweezers

The Advanced Tweezers make use of a coin cell. Even though we have added protections such as the locking screw, there is no reason for this device to be left anywhere that children could get hold of it. Also, the tips are pretty sharp and might cause injury if not used with care.

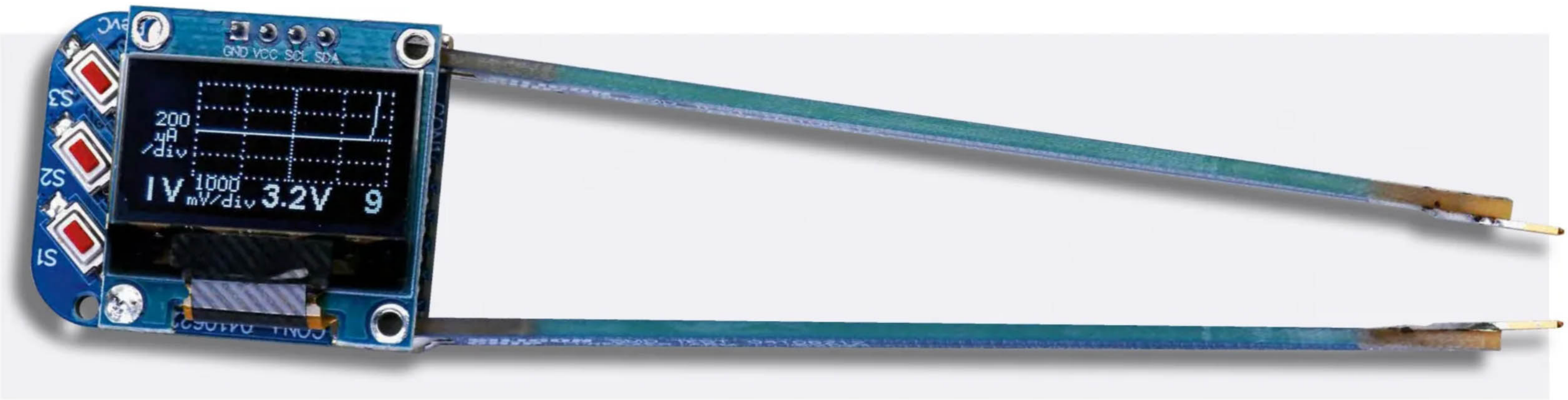
Avoid applying voltages across the Tweezers test tips when it is actively driving them. While this obviously includes the Tone mode, remember that the pins are also driven in the I/V, Auto, Res, Cap and Diode modes.

So be sure that the Tweezers are set to the Meter, Scope, UART or Logic mode before connecting to an external voltage source.

If a glitch causes the Tweezers to reset, they restart in Meter mode to avoid further damage.

Secure with screw
BAT54S x2
D2
D1
Advanced SMD Tweezers 04106221 RevC
SILICON CHIP ©2022

Removal of the coin cell is stopped by a Nylon screw and two nuts.



The arrangement of the arms and tips is much the same as that for the Updated Tweezers, using the same arm PCBs (blue this time) and gold-plated pins as simple, practical tips. This photo shows operation in left-handed mode.

If printing it yourself, it's a good idea to laminate it. Cut along the border to make a shape to match the main PCB. Then use clear neutral-cure silicone or a similar adhesive to secure it to the back of the *Tweezers*. A small amount of glue on each of the arms and the back of the cell holder should be sufficient to hold it in place.

Finally, fit the cell and secure it using the nylon screw and two nuts. Put the head of the screw at the front, on the same side as the switches, so the extra height of the thread at the back blocks the cell from being removed.

Before using the *Tweezers*, we recommend performing some calibration steps, explained just below. We'll also explain all the various modes and how to use them.

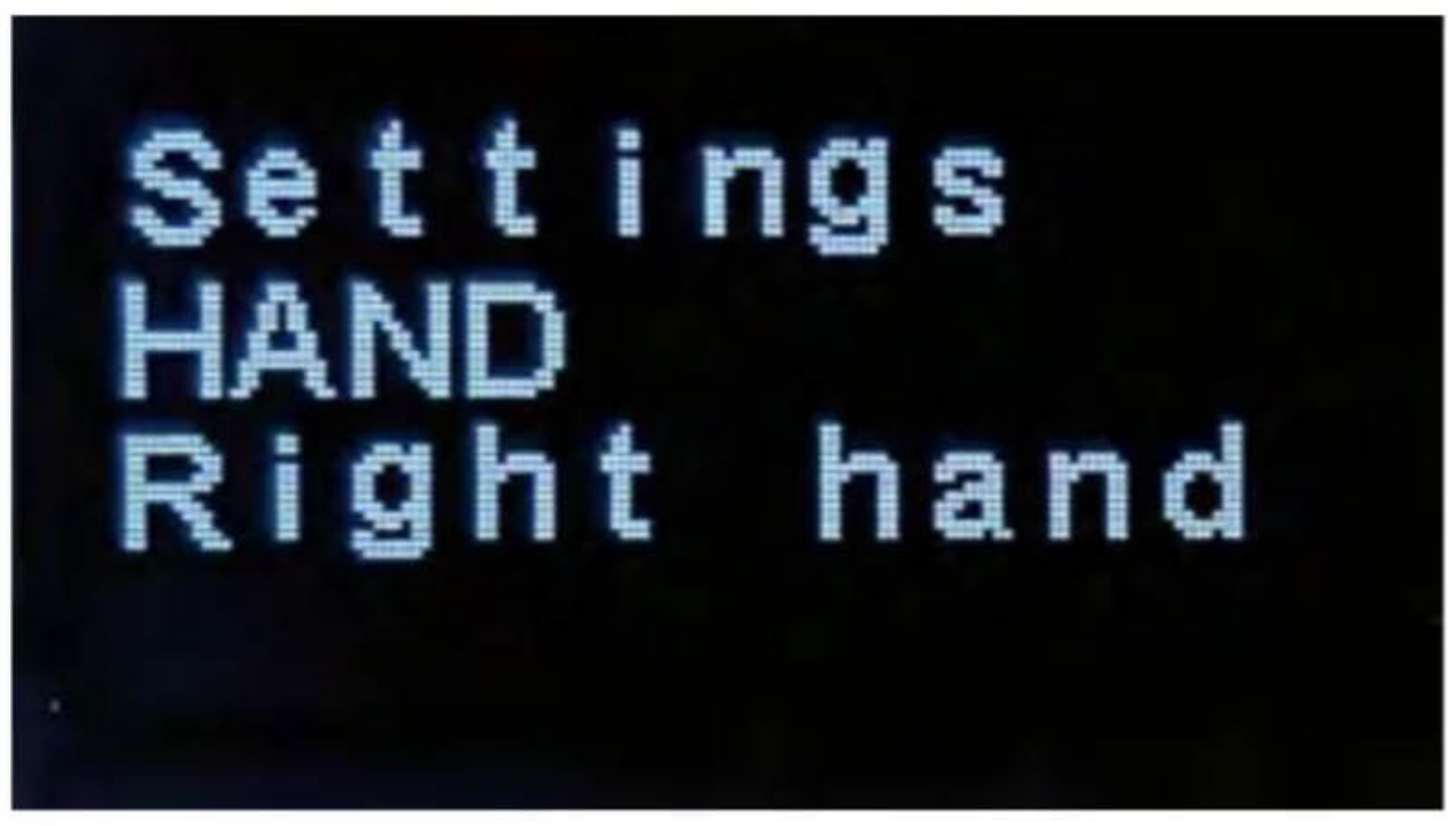
In general, pressing S3 cycles between the various modes, and S1 and S2 have different functions depending on the mode. A long press (more than one second) of S3 changes between Settings and the normal operating modes.

In Settings mode, pressing S3 cycles between the different settings, while S1 and S2 adjust the particular setting, as described on the screen.

Calibration

The calibration procedure has a few steps but is fairly logical. To enter the Settings mode, hold S3 for more than a second and release.

#1 Handedness


Settings
HAND
Right hand

Screen 1: being configured for right- or left-handed operation doesn't change the polarity of the CON+ or CON− connections, but the diode polarity icons will appear relative to the arms.

The first page allows the display orientation to be set to suit either left-handed or right-handed operation – see Screen 1. The setting is toggled by pressing either S1 and S2, and the change occurs immediately.

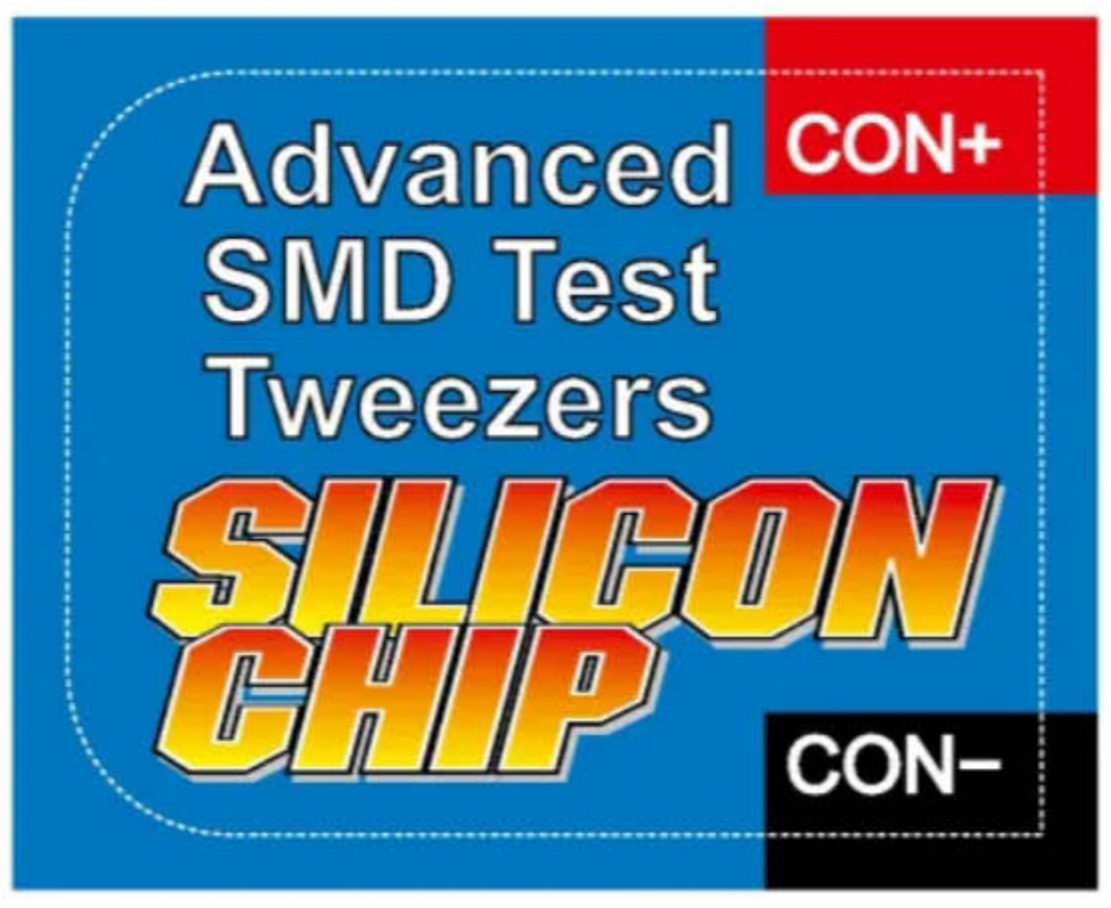
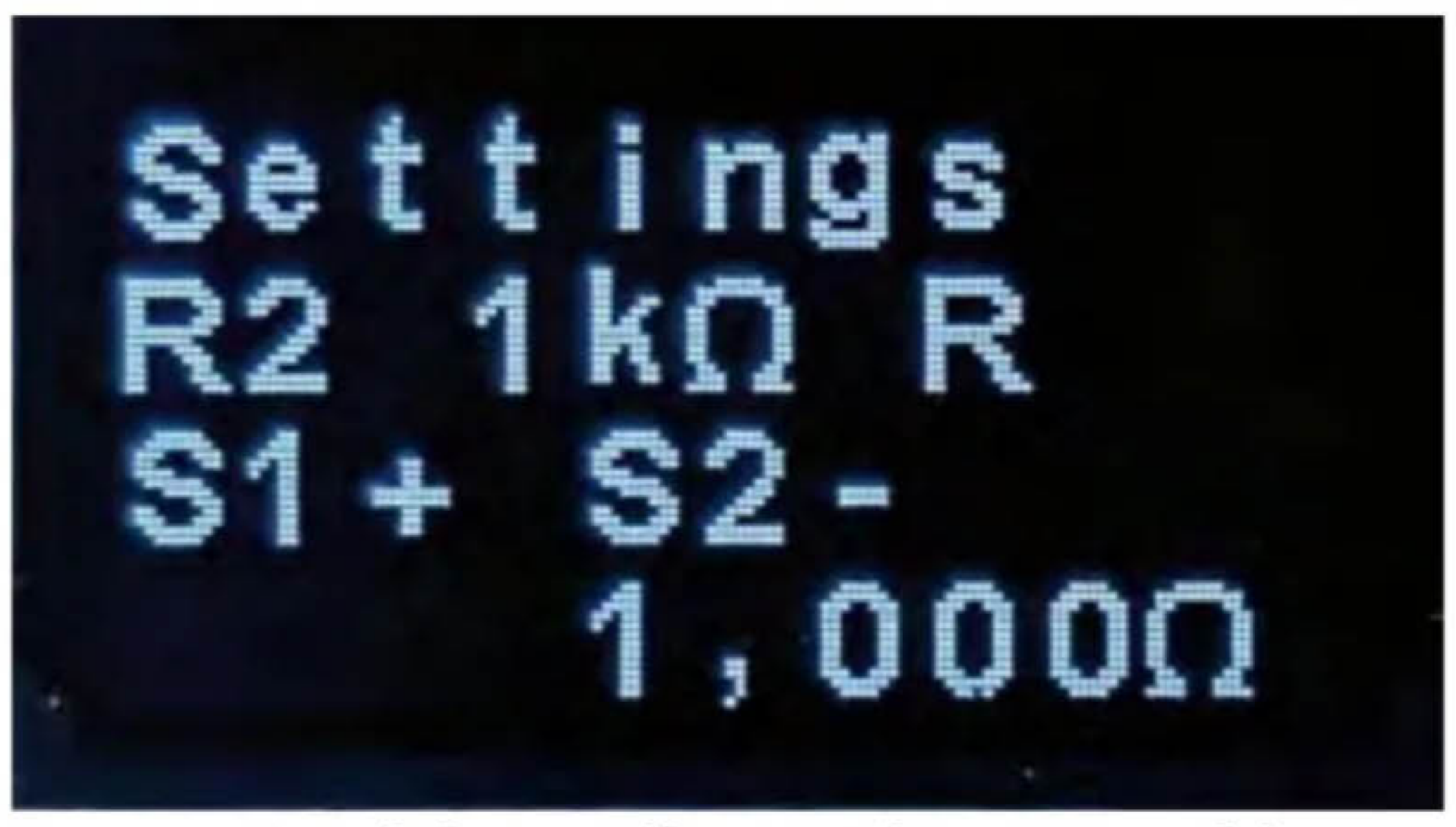


Fig.8: this sticker is for protecting the rear of the Advanced Tweezers PCB. just print the artwork, laminate it, cut it out and glue it to the back of the cell holder. You can of course design your own

All settings like this take effect immediately, so you can test them before being saved to non-volatile flash memory. There is also a Restore option to reload the initial defaults in case of a problem. Pressing S3 cycles to the next page.

#2 Six resistor values


Settings
R2 1kΩ R
S1+ S2-
1,000Ω

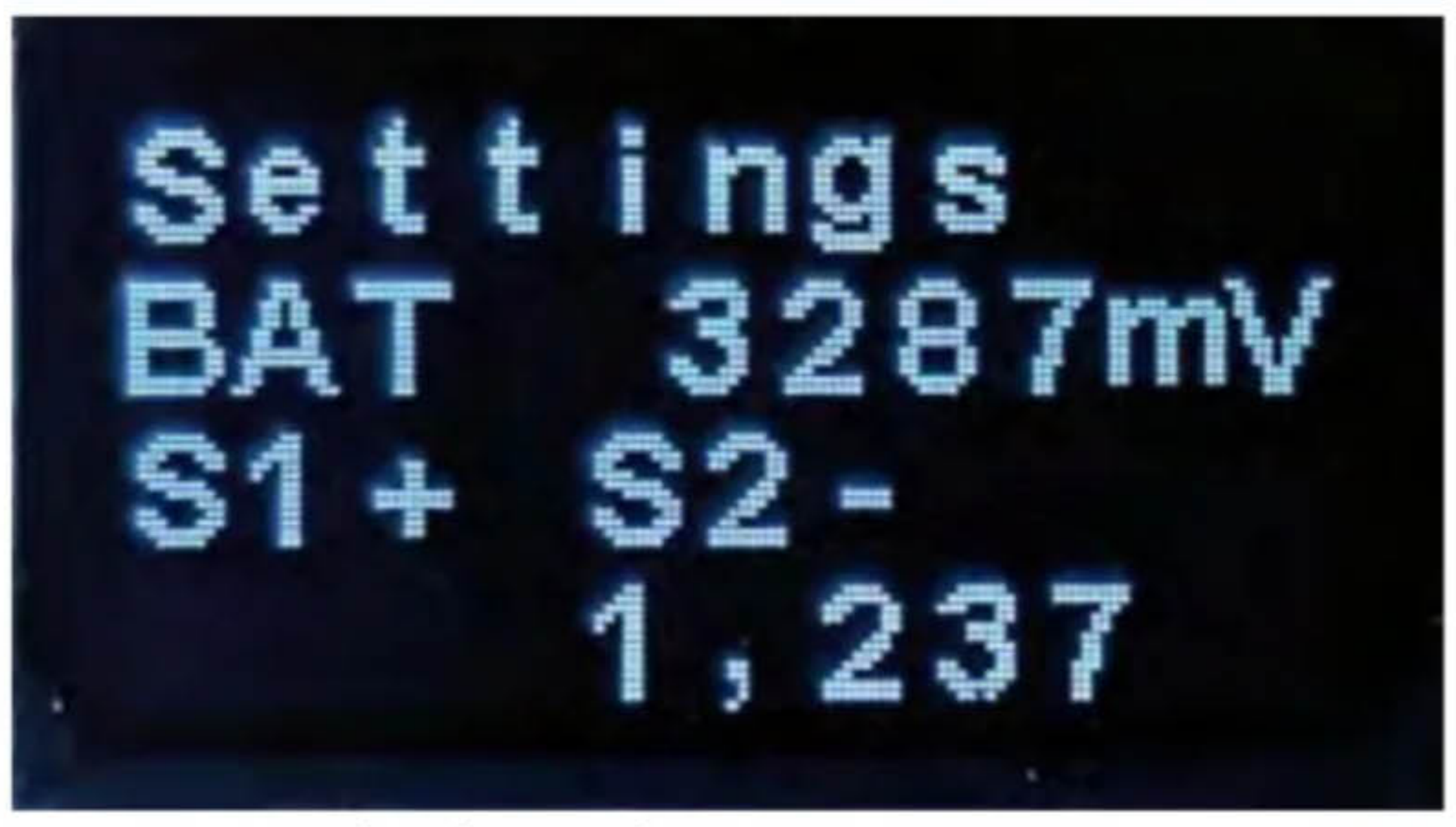
Screen 2: while it will provide reasonably accurate readings without calibration, it is better to enter the exact values of the six most critical resistors (see Fig.5; as measured by a multimeter) on these screens.

The following six pages set the values of the probing resistors you measured earlier, as shown in Screen 2. After the resistor value is an 'L' or 'R', indicating whether you are setting the value of the corresponding resistor on the left or right side of the main PCB.

The values are adjusted in steps of 0.1%, ie, 1Ω for the 1kΩ resistors, 10Ω for the 10kΩ resistors and 100Ω for the 100kΩ resistors. Use S1 and S2 to adjust these values, and then press S3 to step to the next.

On all pages like this, S1 will increase the displayed value and S2 will decrease it. Brief presses will make single steps, but holding the button in will cause it to increment or decrement about ten times per second.

#3 Internal reference voltage


Settings
BAT 3287mV
S1+ S2-
1,237

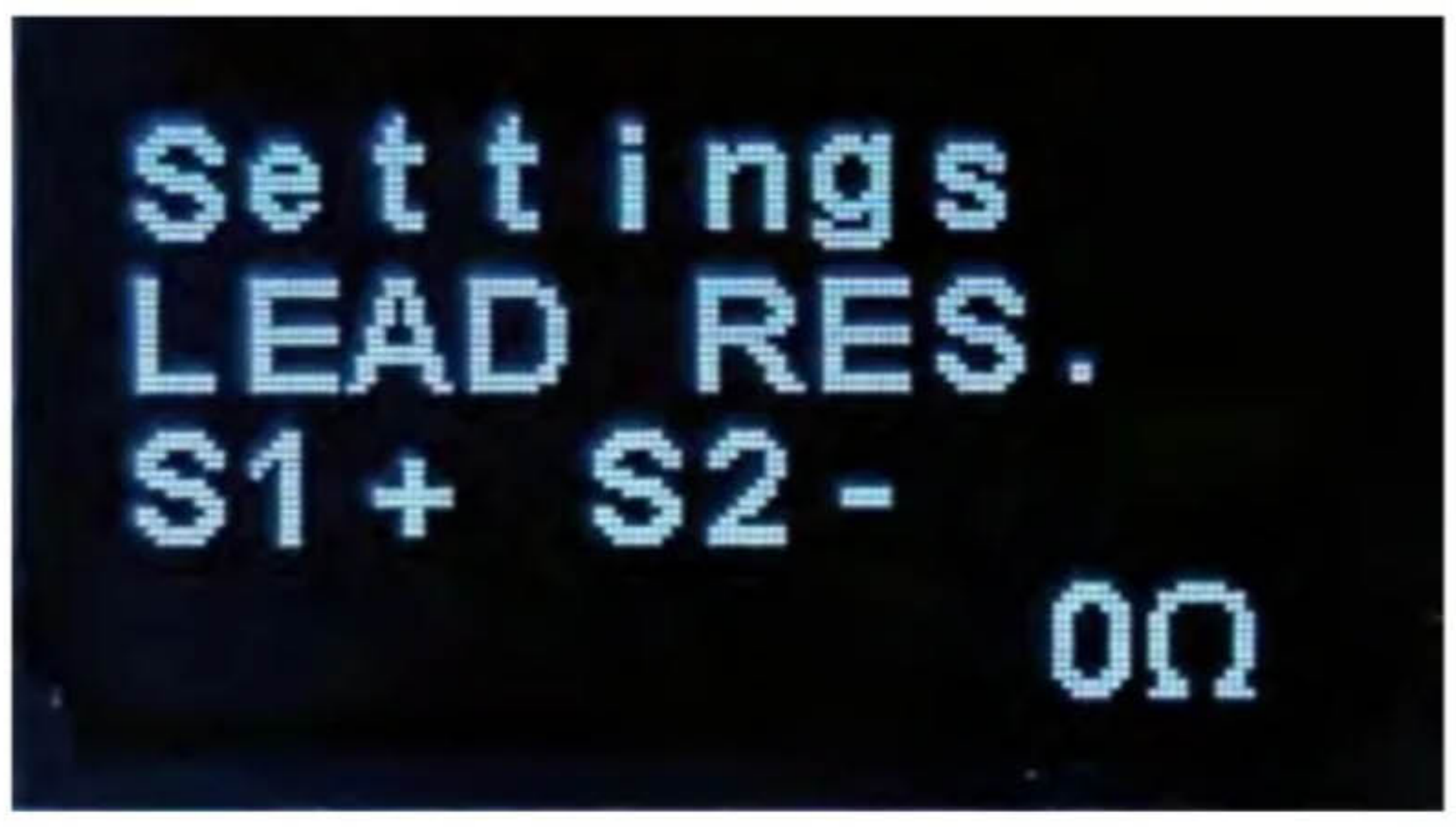
Screen 3: diode and capacitor measurements will be most accurate if the internal bandgap reference is calibrated. Adjust it using S1 and S2 until the displayed cell voltage is correct.

The BAT page (Screen 3) calibrates the internal reference, which is nominally 1200mV and is shown at the page's bottom. The value on the second line is the calculated cell voltage based on the reference setting.

Trimming this parameter is best done with a multimeter. Measure the actual cell voltage (which can be measured at pins 2 and 3 of the ICSP header) and adjust the displayed cell voltage until it matches.

The voltage shown in Screen 3 is higher than might be expected from a coin cell, as we were using a 3.3V supply for testing. In this case, the reference voltage has been trimmed upwards by about 3%, from 1200mV to 1237mV.

#4 Lead/tip resistance

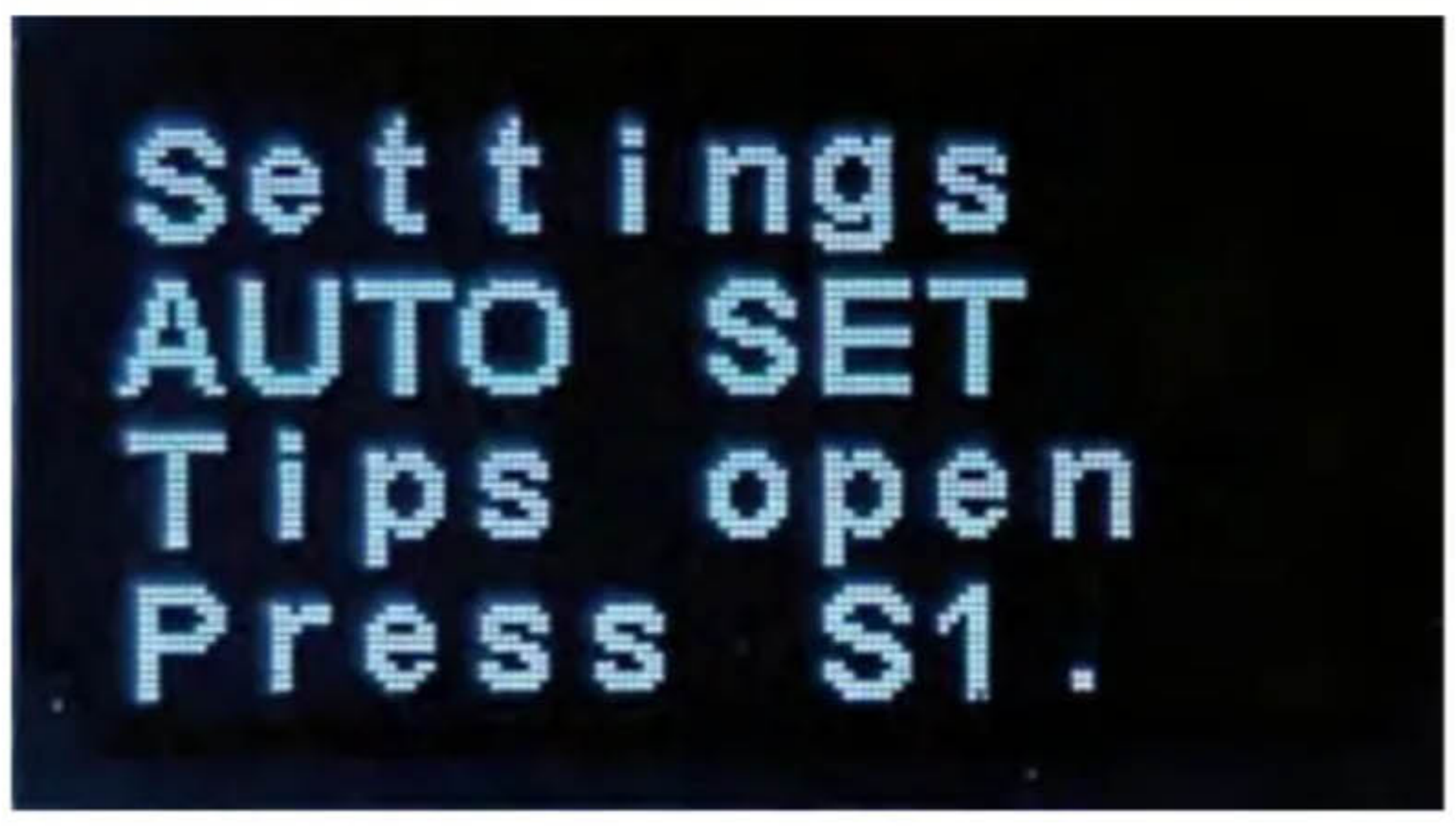

Settings
LEAD RES.
S1+ S2-
0Ω

Screen 4: the lead resistance was close to 0Ω in our prototype, but this setting might be handy if you are working with breadboards and jumper wires with significant resistance.

The next page (Screen 4) sets the lead resistance, which defaults to 0Ω. Our prototypes had less than 1Ω of lead resistance and so were accurate enough; thus, you probably do not need to change this. You can test this by pressing the tips together on a mode that displays resistance.

If you are connecting extra leads or jumper wires and breadboards, you can account for the higher resistance with this setting.

#5 Auto calibration



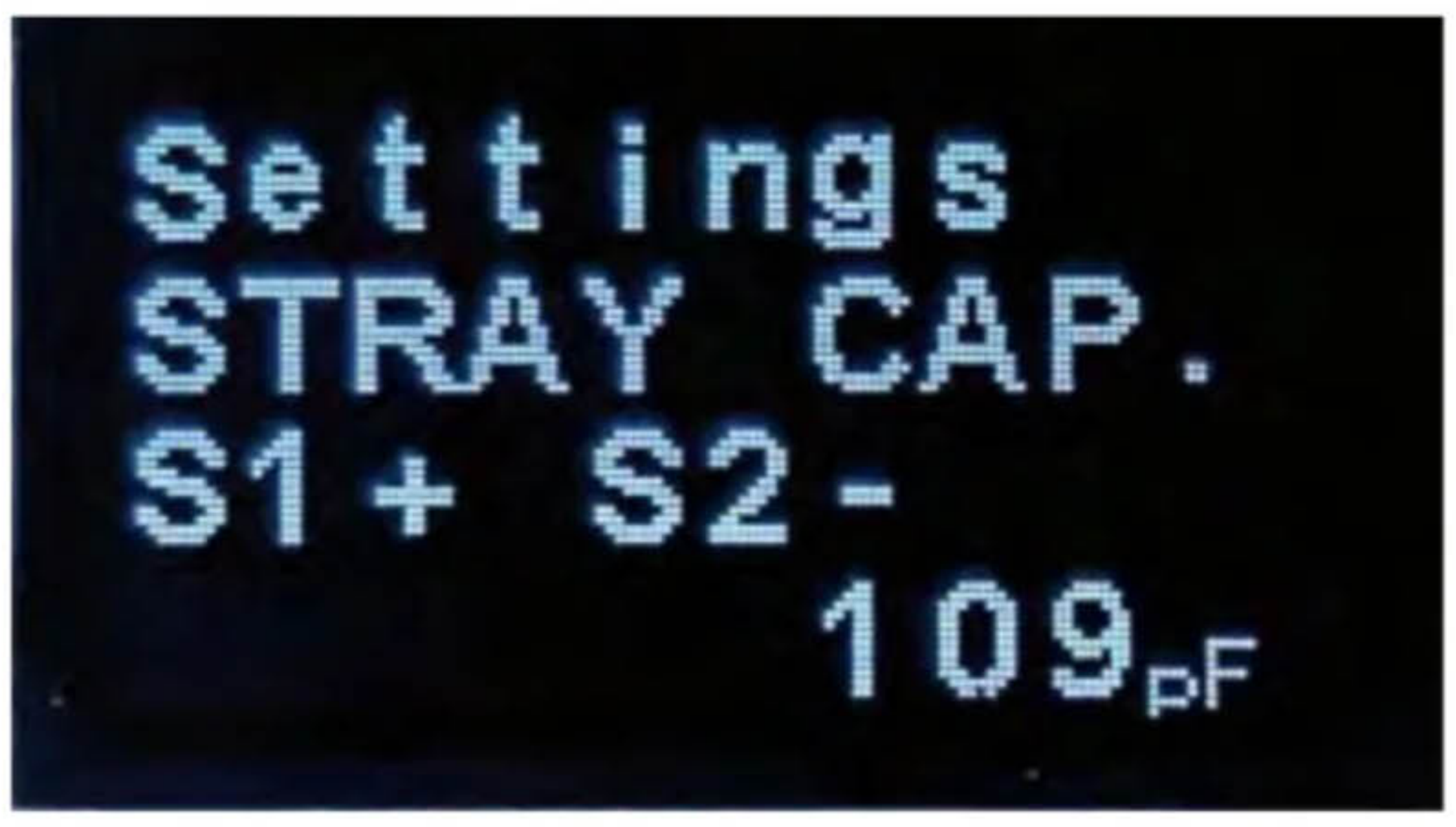
```
Settings
AUTO SET
Tips open
Press S1.
```

Screen 5: the AUTO SET tunes three calibration parameters by performing internal measurements with the tips open. It depends on the previous calibration settings being entered and correct.

The next page (Screen 5) provides the option to AUTO SET several parameters, namely stray capacitance, Meter offset and CTMU trim. These require the tips to be left open and not connected to anything, and are only accurate when the previous settings (ie, the test resistances and internal reference voltage) have been calibrated.

Hold the *Tweezers* as you usually would to take into account the stray capacitance of your hand. Then press S1 to start this process. It takes less than a second and you can review the values on the subsequent pages by pressing S3.

#6 Stray capacitance

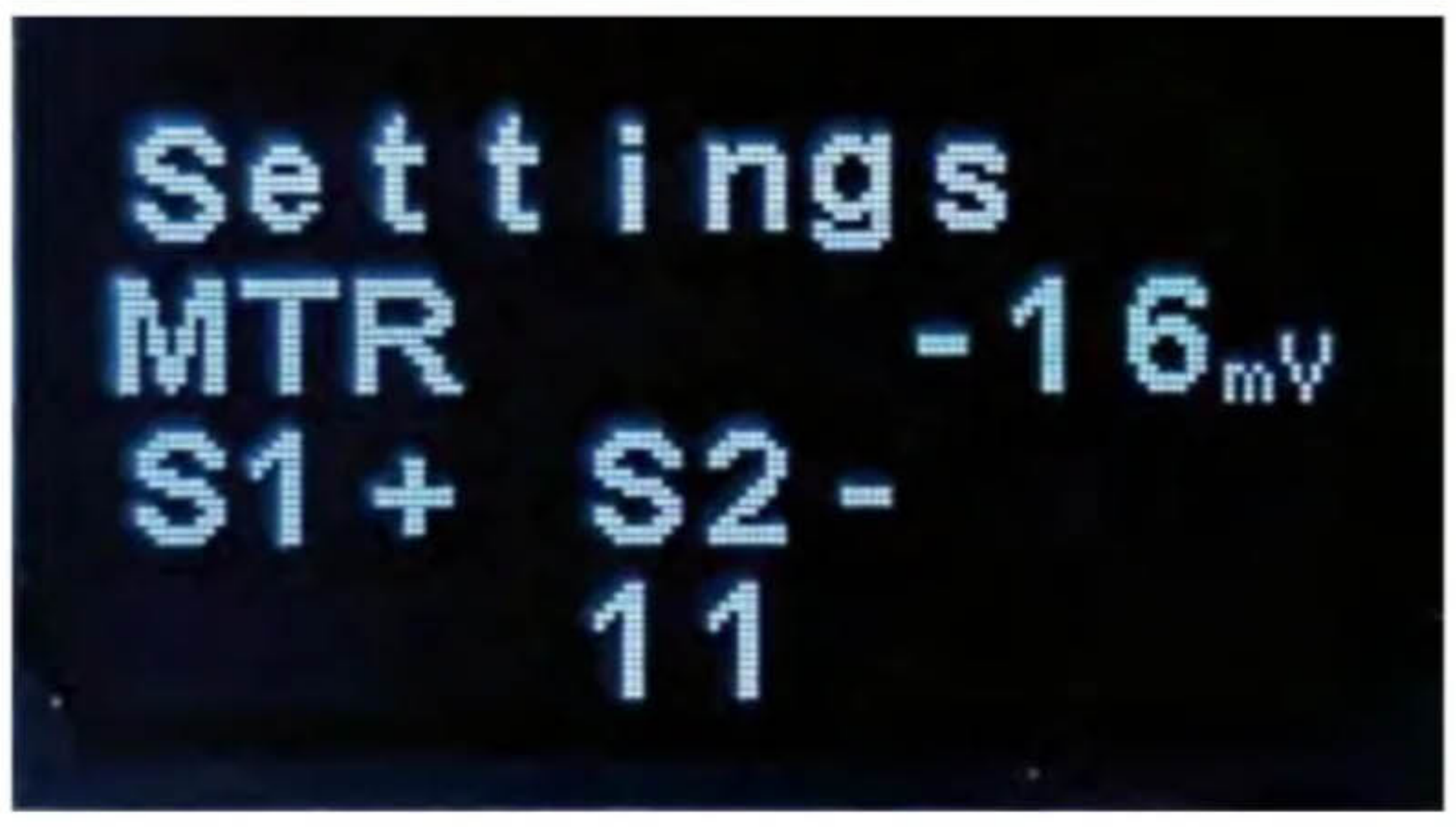


```
Settings
STRAY CAP.
S1+ S2-
     109pF
```

Screen 6: stray capacitance can be tuned automatically or entered manually; it should be around 100pF. You can check it varies by setting it to 0pF and watching the value on the Cap screen.

The stray capacitance of our prototype is around 100pF; check that you have a similar value, as seen in Screen 6. A vastly different value might indicate a problem; for example, you may have a resistor in the wrong location.

#7 Meter offset



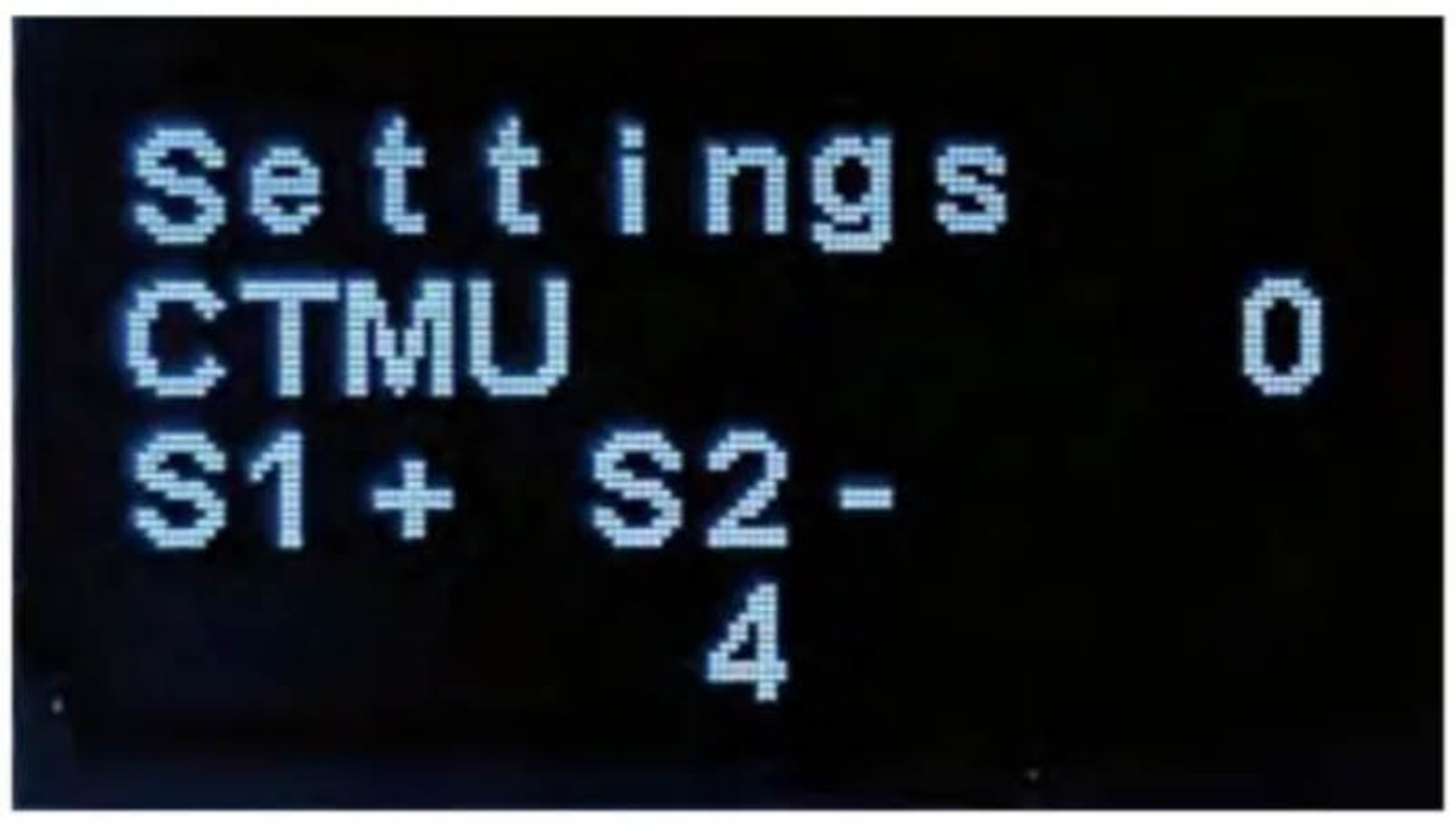
```
Settings
MTR     -16mV
S1+ S2-
      11
```

Screen 7: Meter offset adjusts for any difference in the two 1kΩ/1kΩ dividers and is set by the AUTO SET page. The 16mV error is noise in the ADC measurement, being a single ADC step.

The Meter offset adjusts the relative value of the four lower 1kΩ resistors; it is effectively the difference between the midpoints of the two voltage dividers shown in Fig.4 last month. The value at the bottom is the number of ADC steps used to adjust the reading.

In Screen 7, you can see the actual Meter reading at top right. You can validate this by verifying that the reading hovers close to 0mV when the tips are open. The –16mV seen corresponds to a single ADC step, and thus the resolution in this mode.

#8 Current source trimming



```
Settings
CTMU       0
S1+ S2-
      4
```

Screen 8: the CTMU's current source is also trimmed by the AUTO SET page but has very coarse trimming, with 2% steps. You can observe this by manually adjusting the trim value on this page.

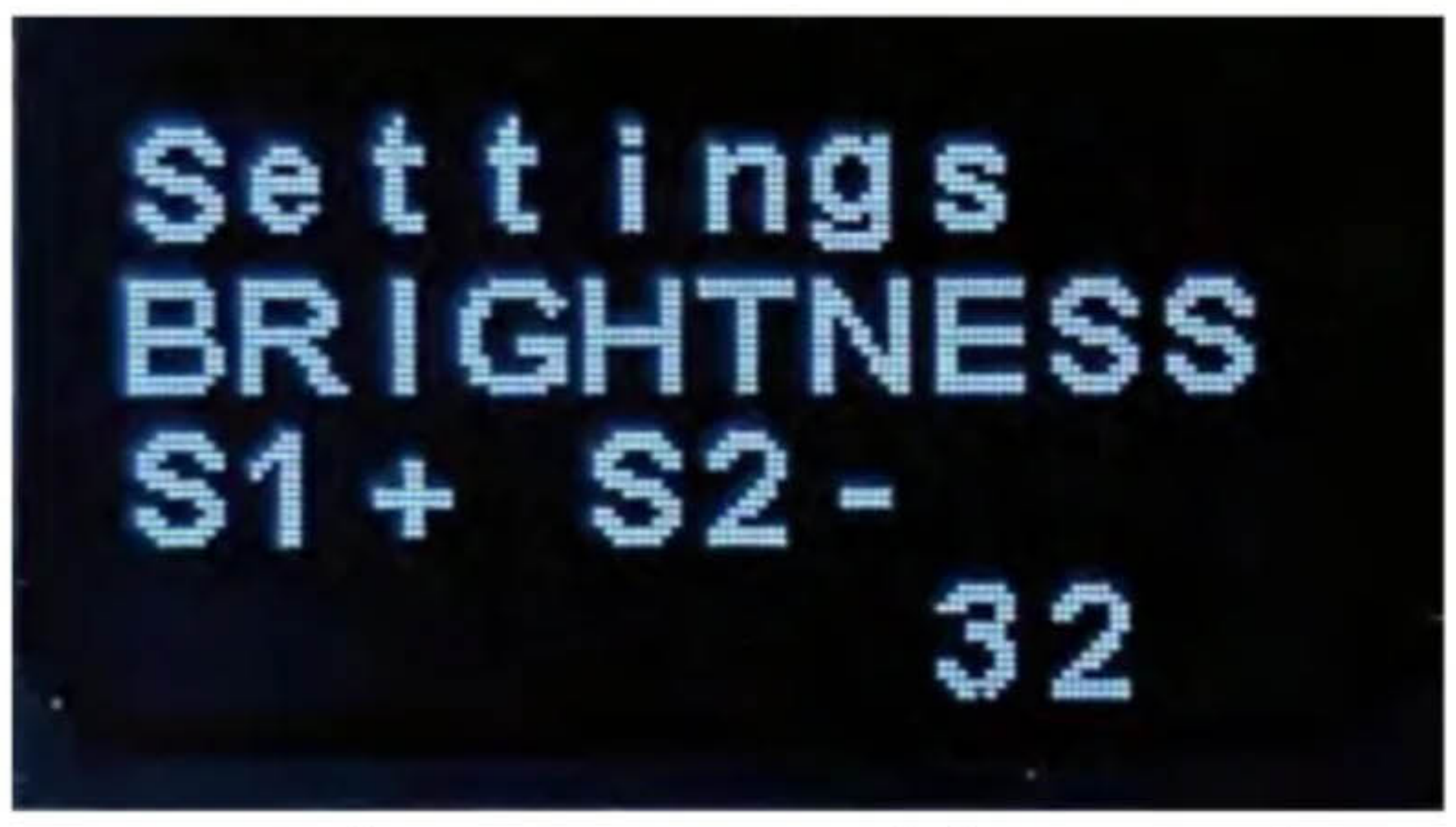
The CTMU current source, used for capacitance measurements, can be trimmed via Screen 8.

The lower value is the degree of trimming, with each step being a delta of about 2%. This is a hardware limitation and is a significant factor in limiting the accuracy of capacitance measurements.

The value shown at upper right is the deviation of the measured current from its nominal value on the 550μA scale, while the lower number indicates the amount of trimming, with zero being the default. With a 2% deviation, the steps are around 11μA apart, so a setting within about 5μA of zero is optimal.

Note that the Meter reading depends on the internal bandgap reference voltage being set correctly, as does the CTMU trim. The CTMU trimming procedure uses one of the 1kΩ resistors and thus depends on its actual resistance too. So ensure these values are set before running the AUTO SET process.

#9 OLED brightness

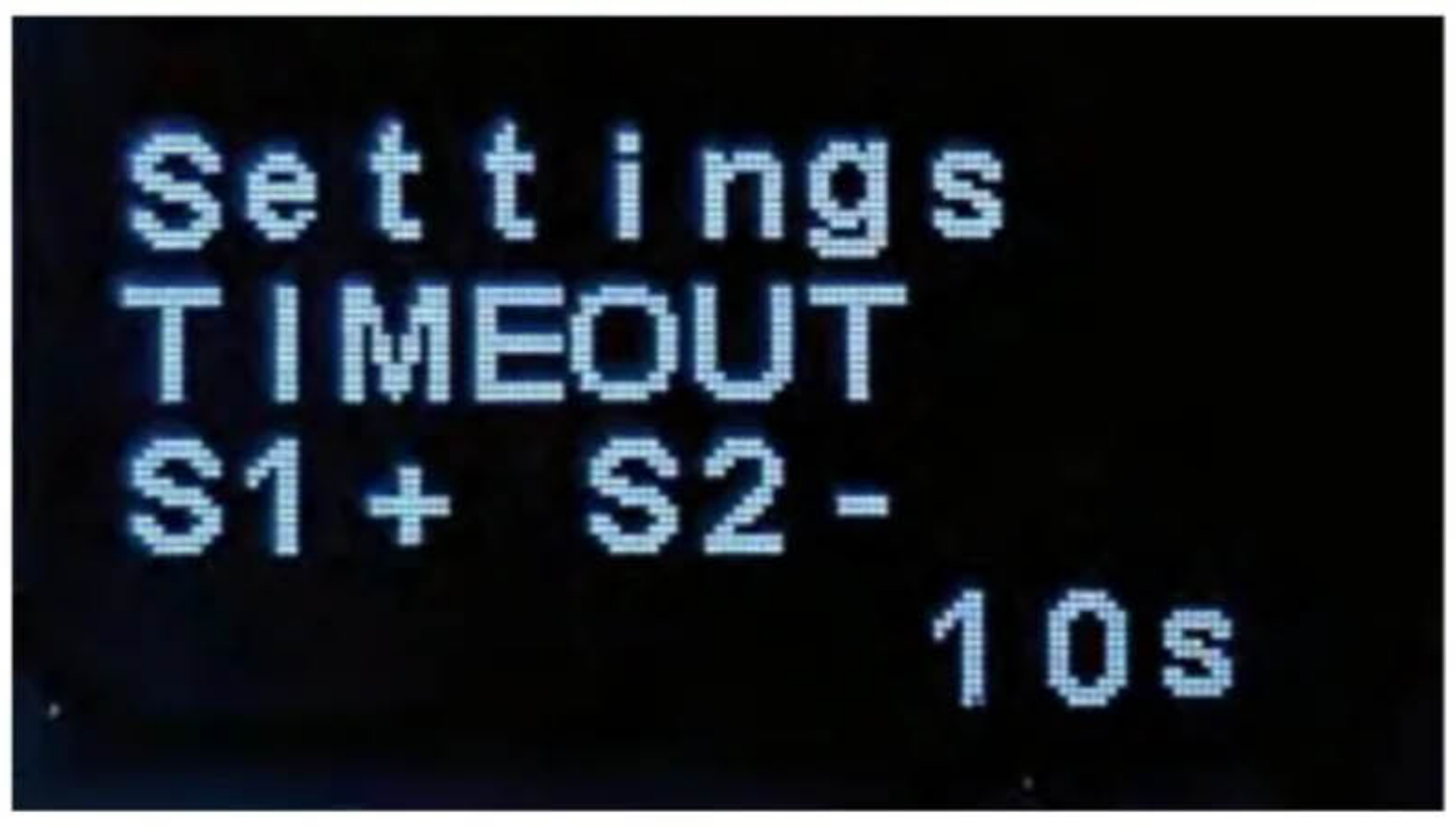


```
Settings
BRIGHTNESS
S1+ S2-
        32
```

Screen 9: the OLED is one of the major drains on the coin cell, so a low brightness setting increases the cell life. We had no trouble using the Tweezers with the OLED set to quite a low brightness.

On Screen 9, the display brightness can be set between 32 and 255, with 64 being the default. This setting is a compromise between display visibility and cell life. You should set this to the lowest level at which you can still read the screen clearly.

#10 Screen blanking timeout



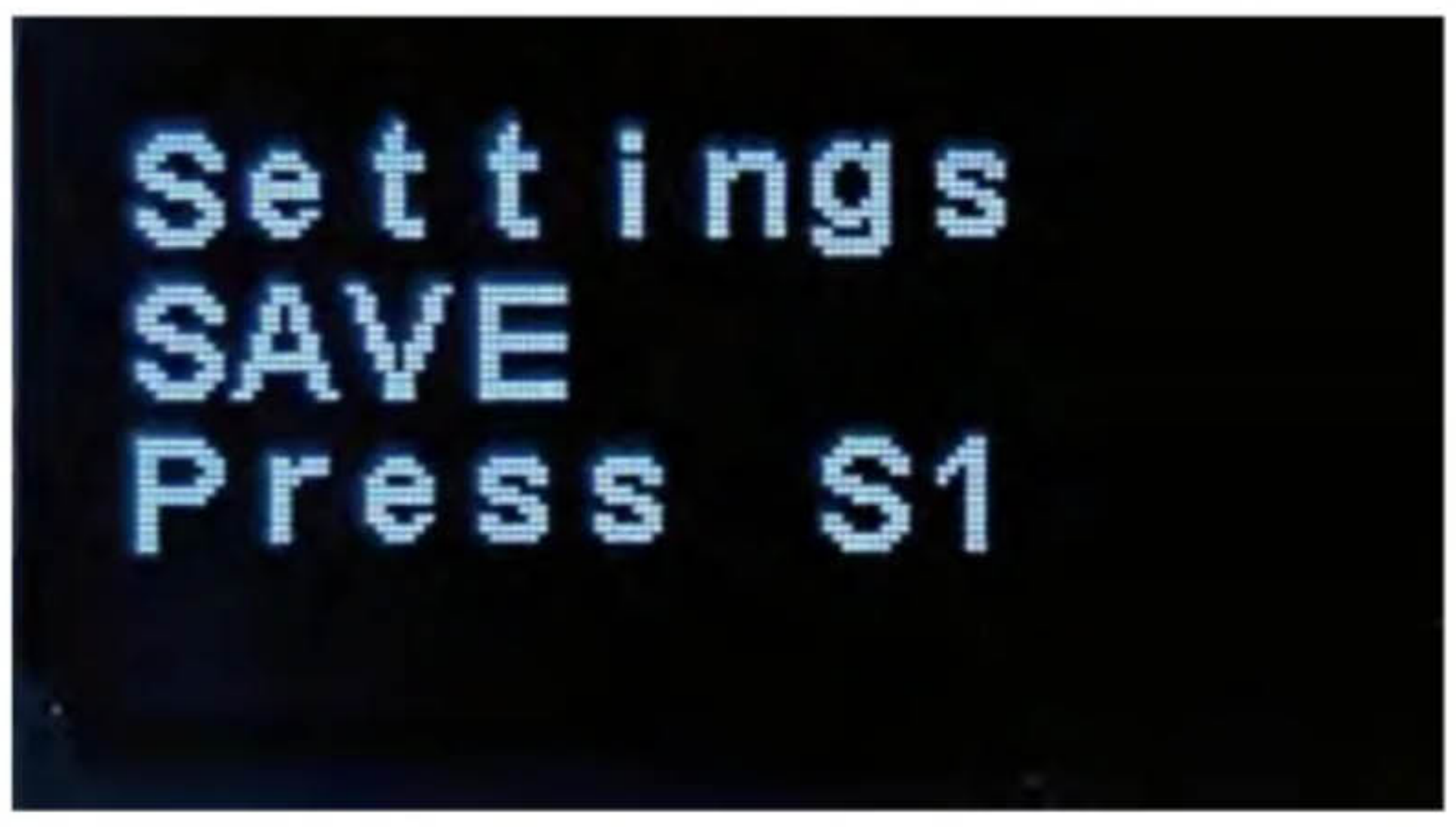
```
Settings
TIMEOUT
S1+ S2-
       10s
```

Screen 10: with an option to disable the timeout in all modes, the timeout value is less critical than on the earlier Tweezers. The default is 30s, but it can be set from 3s to 99s to suit your needs.

Screen 10 sets the display Timeout and is the countdown (in seconds) before the *Tweezers* enter their low-power sleep mode after the last button press. This value can be set between 3 and 99 seconds, with a default value of 30s.

Note that the operating screens all have the option to freeze the timer so that the *Tweezers* can be used continuously when required.

#11 Save settings to flash

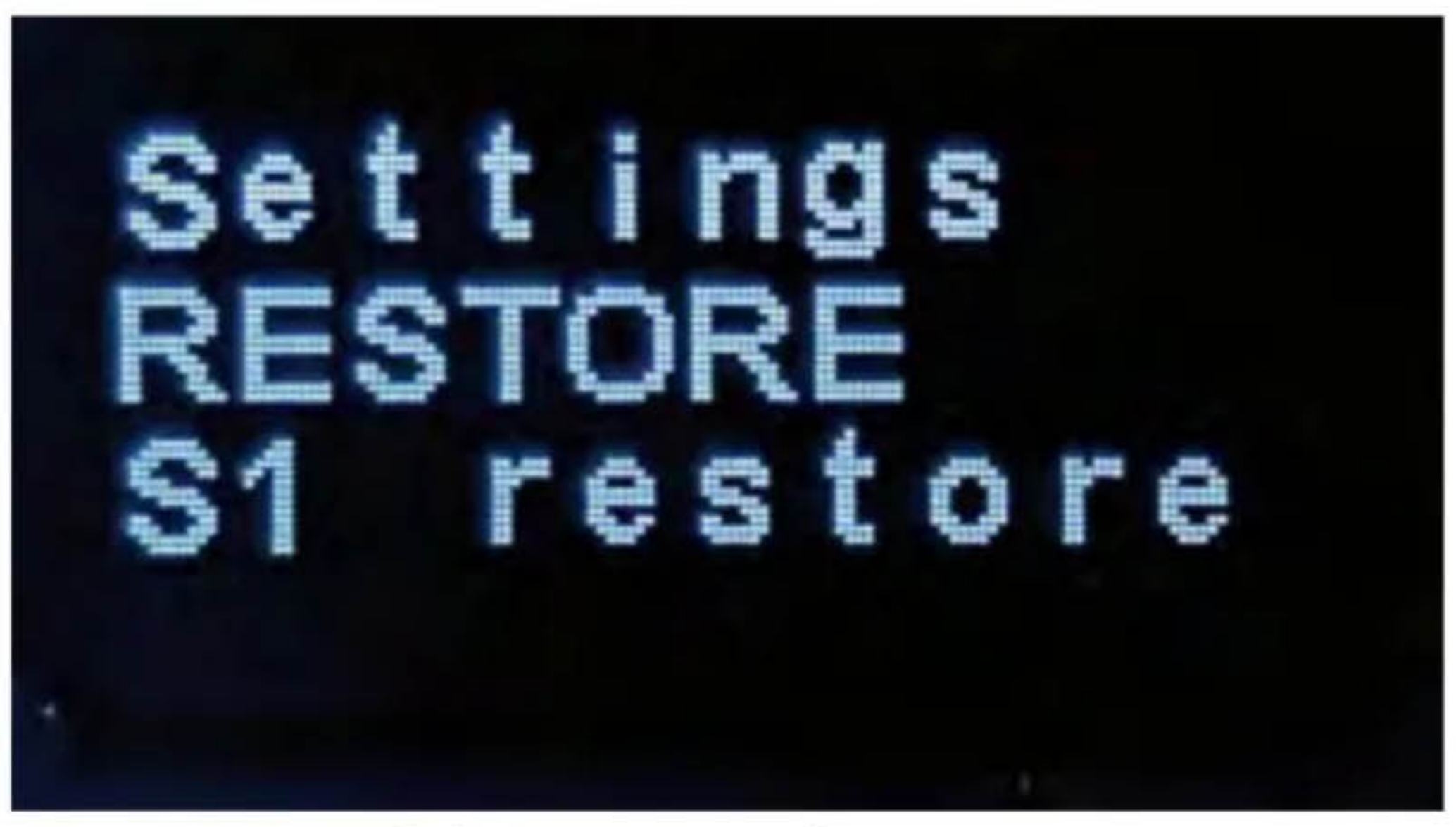


```
Settings
SAVE
Press S1
```

Screen 11: all calibration and operation parameters are live as soon as they are set. On this page, you can press S1, then S2 to save them to flash memory so you won't have to repeat the calibration.

Screen 11 gives the option to Save the calibration settings to flash memory. On this page, press and release S1 and then S2 to save the data. You should do this once the *Tweezers* are set up to your liking.

#12 Restore settings from flash


Settings
RESTORE
S1 restore

Screen 12: if the settings become corrupt, the Restore option will load defaults from a backup location. You can also load flash defaults by holding S3 while powering on the Tweezers.

The Restore page (Screen 12) can be used to reload the default settings from a backup copy. These settings are put into use straight away.

Although it would be very unusual, it's possible for the saved settings in flash to be corrupted.

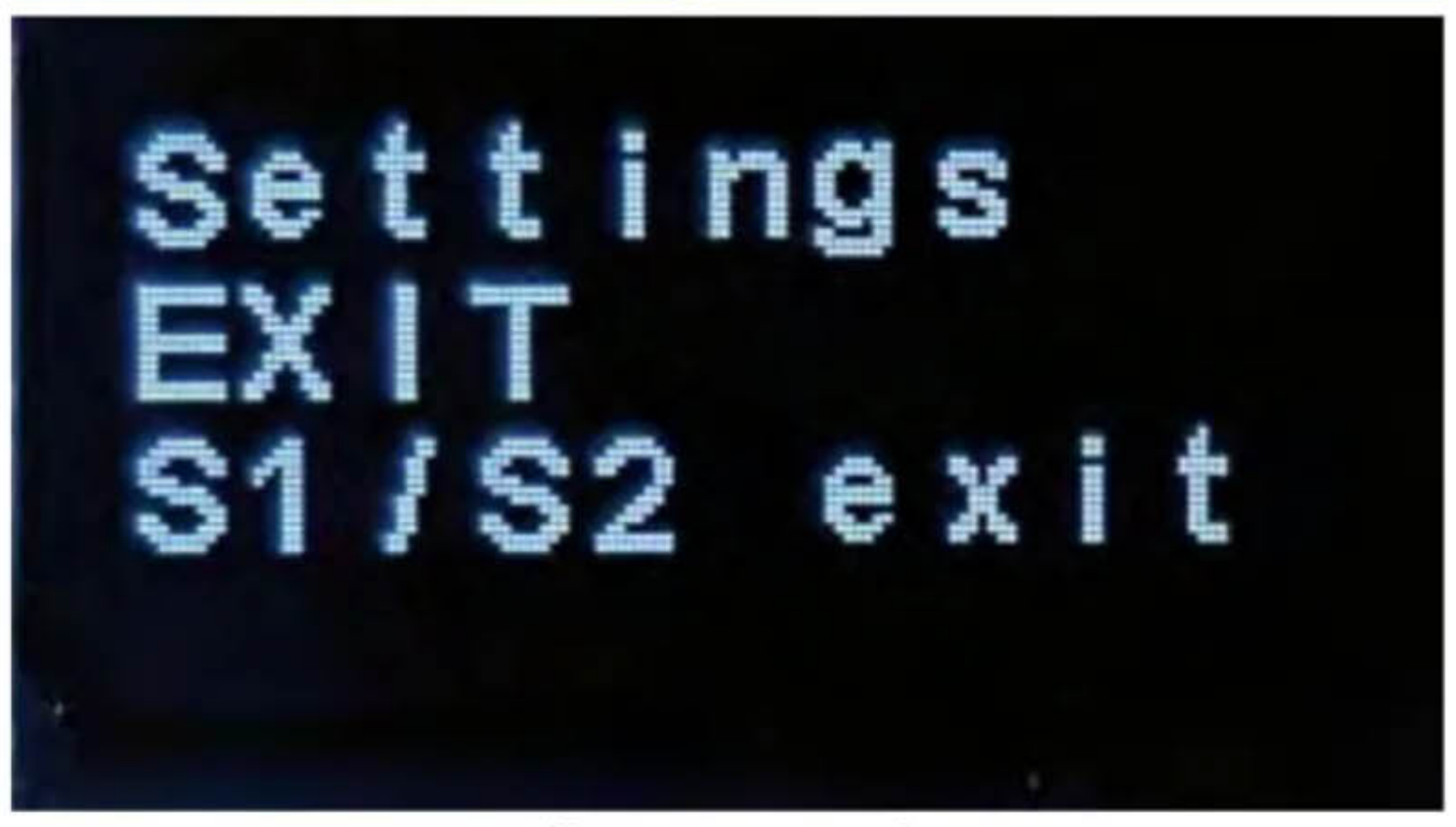
This scenario might happen if, for example, power is lost while writing to flash. Such corruption can be detected by the micro and then trapped to avoid improper settings being used.

If you get a 'Flash Error' message when powering up the *Tweezers*, then remove the cell and hold S3 in while reinserting it (giving a 'No Flash' message).

This bypasses the loading of the settings from flash, after which you can use the Restore and Save pages to reload and rewrite the flash memory with uncorrupted data.

You should then treat the *Tweezers* as if they have not been calibrated and repeat the calibration procedure.

#13 Exit settings


Settings
EXIT
S1/S2 exit

Screen 13: as well as using this screen, you can also leave the Settings pages at any time by pressing and holding S3 for more than a second. A brief press of S3 will take you back to the first Setting.

Last, Screen 13 shows the final Exit page that allows you to press either S1 or S2 to return to the operating mode, while S3 will return to the first Settings page. Note that a long press on S3 at any time will also exit Settings mode.

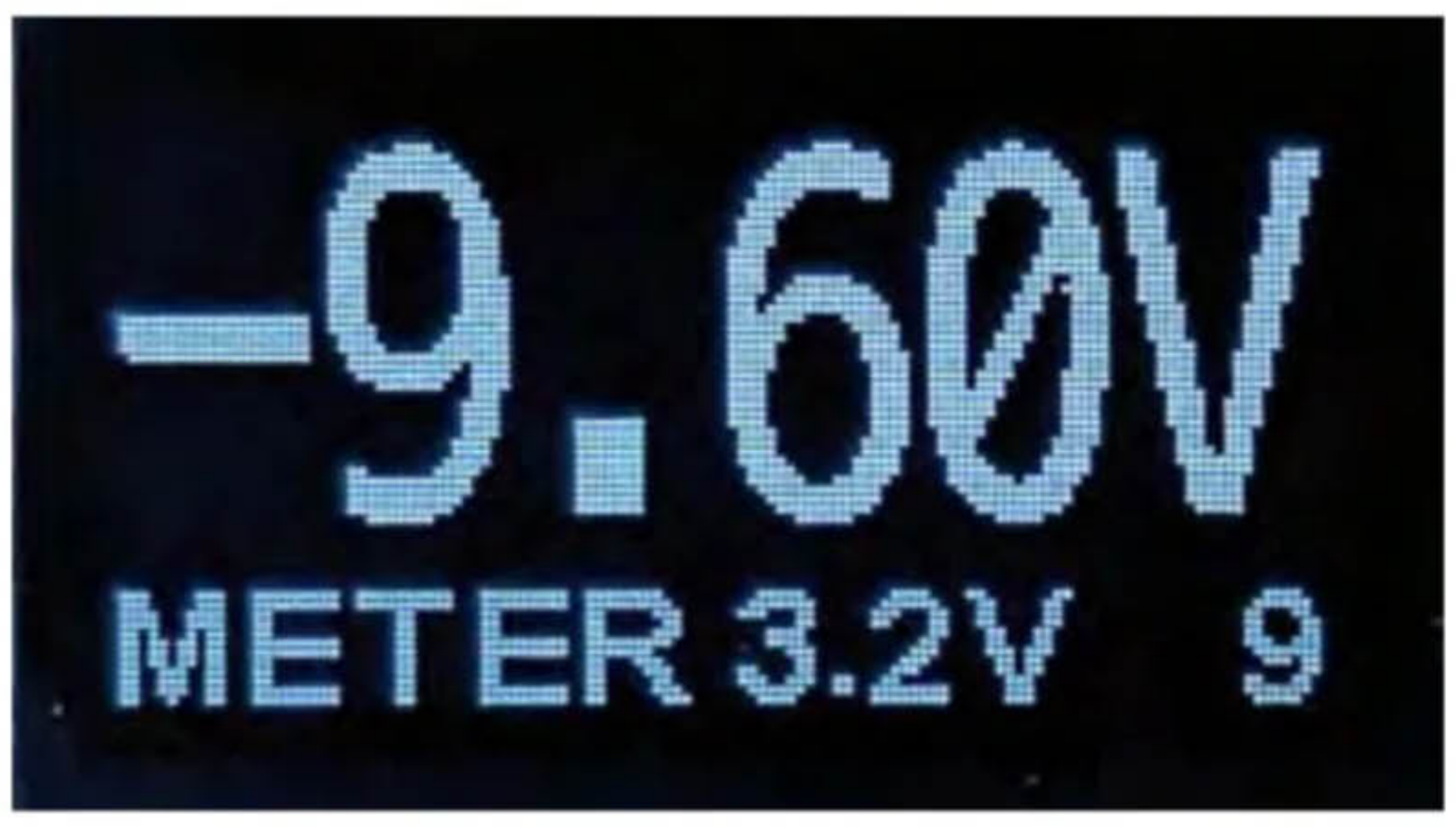
Operation

During operation, the bottom line in all modes shows data that always has the same format. From left to right, it shows the current mode, the cell voltage and a countdown timer.

If the timer is flashing, it has been paused and does not count down, allowing continuous operation.

When the timer counts down to zero, the *Tweezers* will enter the low-power sleep mode with a blank display. Pressing any of S1, S2 or S3 will reset the timer and resume normal operation.

#1 Meter mode

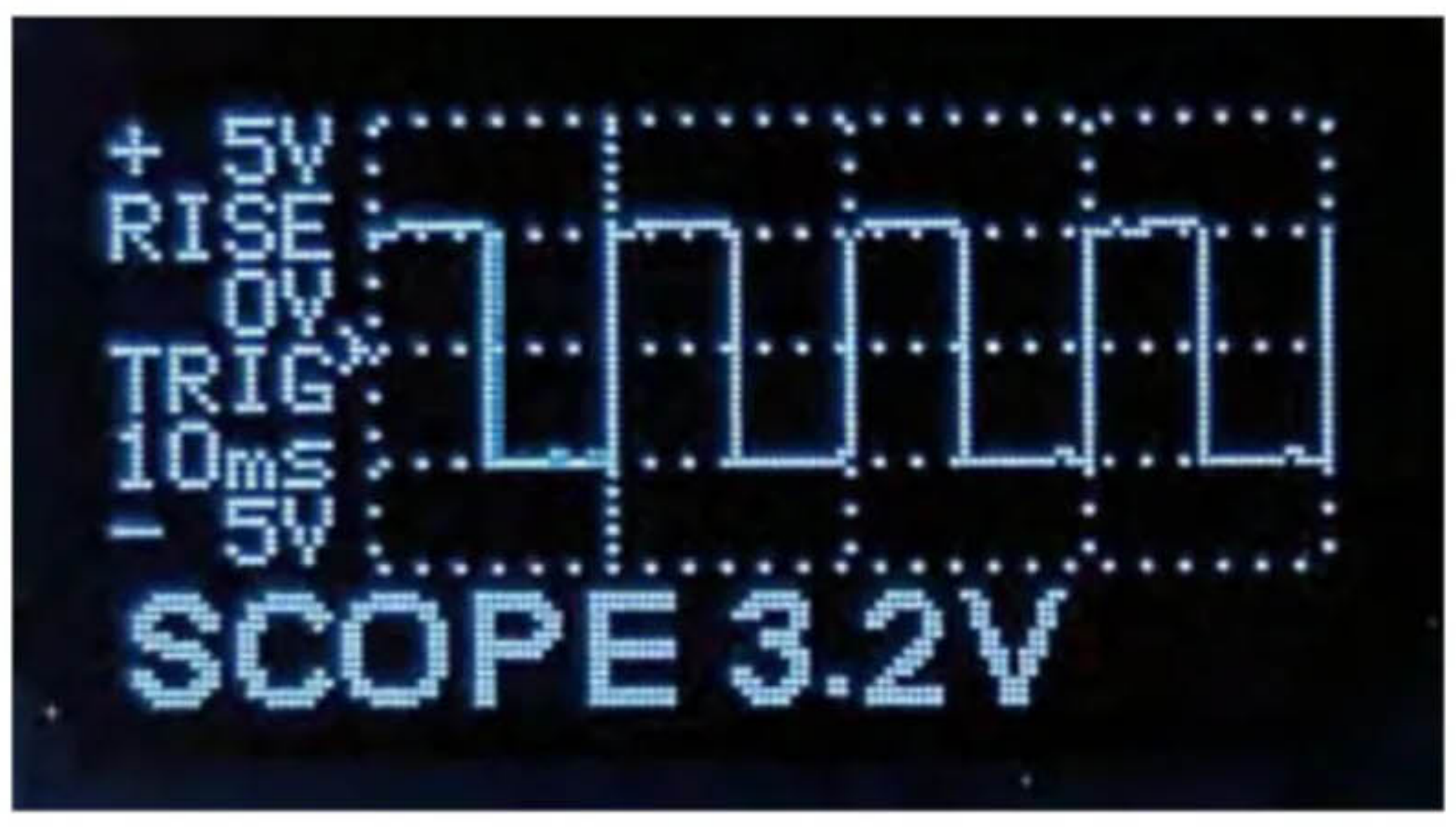

-9.60V
METER 3.2V 9

Screen 14: the initial Meter display mode, which can read up to 30V with both negative and positive polarities (with respect to CON+ and CON−). The resolution is 10mV to 9.99V and 0.1V above that.

The *Tweezers* start on the Meter screen, which displays the measured voltage between the probe tips. Screen 14 shows the *Tweezers* in Meter mode, connected to a fresh 9V battery.

Pressing S1 in this mode will pause the sleep counter and pressing S2 will resume it. As is typical, any button press will also reset the sleep counter. Pressing S3 cycles to the next mode.

#2 Scope mode


+ 5V
RISE
0V
TRIG
10ms
- 5V
SCOPE 3.2V

Screen 15: Scope mode is handy, even though there are only 100 horizontal and 48 vertical pixels in the trace area. It samples at up to 25kHz, is suitable for audio use, and has adjustable trigger settings.

The Scope mode is shown in Screen 15, with a nominally 100Hz 6V peak-to-peak waveform. this was fed to the *Tweezers* using a second set of *Advanced Tweezers* which were set to the Tone mode.

This has various parameters to set; pressing S1 cycles between the parameters, while S2 adjusts the selected parameter by cycling between the available options.

You can see which parameter is selected as it will be flashing. These include the vertical axis maximum (voltage), trigger mode (RISE, FALL, BOTH or AUTO), trigger level in volts, timebase per division and whether the vertical axis minimum is 0V or the negative of the maximum.

Pressing S1 also cycles through the countdown timer. Note that while it is selected, the countdown timer is paused.

The trigger point is fixed at the first time division, which is marked by a more solid vertical graticule.

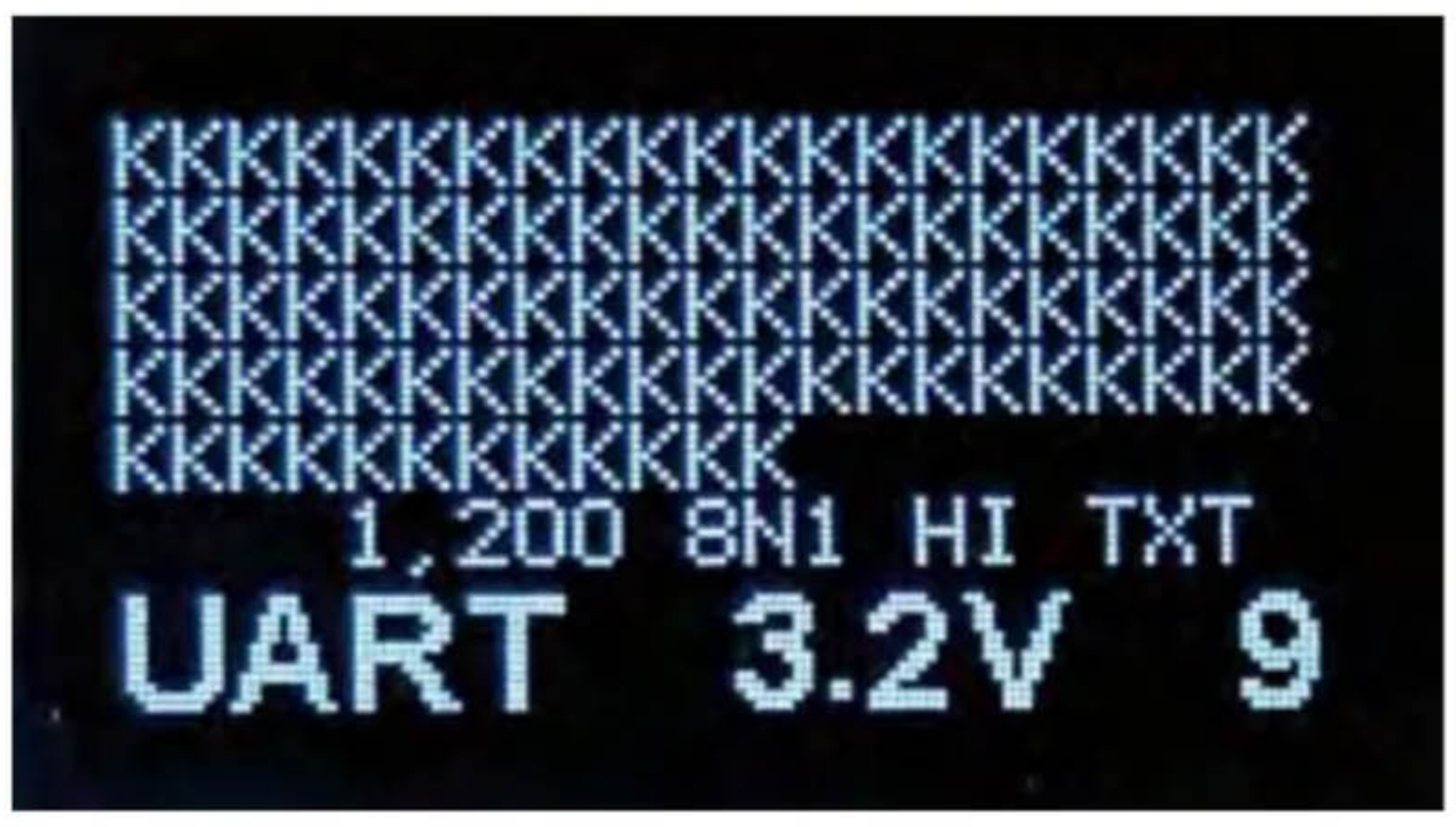
Thus, one time division is displayed before the trigger point and three after. A tiny arrowhead also marks the trigger voltage level to the left of the grid area.

Due to the slow update speed of the OLED display, the trace is not displayed live. Instead, a sample set is taken, spanning around two full screen widths. It is checked for trigger conditions and an appropriate portion is displayed.

If no trigger is found (or AUTO trigger mode is selected), the first screenful of samples taken is displayed, along with a 'WAIT' message. If a trigger is found, then the trigger point is aligned with the graticule and 'TRIG' is displayed.

Since a complete sample set at some of the longer time divisions can take several seconds, it can be a while before data is displayed.

#3 UART serial decoding


KKKKKKKKKKKKKKKKKKKK
KKKKKKKKKKKKKKKKKKKK
KKKKKKKKKKKKKKKKKKKK
KKKKKKKKKKKKKKKKKKKK
KKKKKKKKKKK
1,200 8N1 HI TXT
UART 3.2V 9

Screen 16: we find the UART Serial Decoder indispensable at times. Like the Scope mode, it is highly configurable in terms of baud rates, bit depth and data polarity. This shows the TXT view.

The next mode is the Serial Decoder, labelled 'UART' (see Screen 16). The bottom text shows the current settings, which are similar to those in Scope mode. S1 cycles between the parameters (including the sleep timer) while S2 adjusts the selected, flashing parameter.

The first setting is the baud rate, which includes standard rates from 110 to 115,200 baud. The second setting is the format, which can be eight bits with odd, even or no parity, or

Secure with screw
D2
D1
BAT54S x2
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Advanced SMD Tweezers
04106221 RevC

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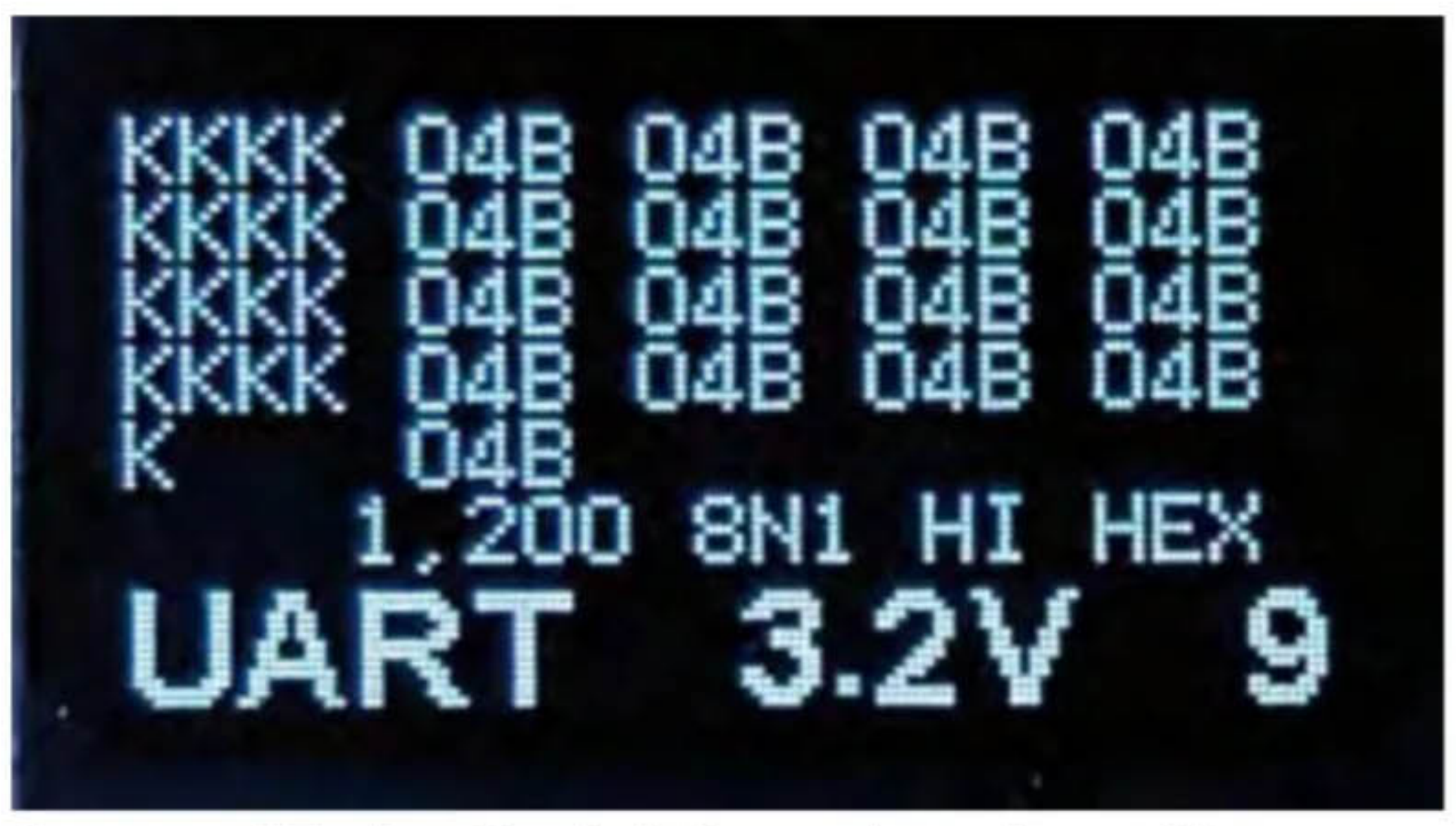
The underside of the Advanced SMD Test Tweezers (shown larger than actual size) is mostly empty, with only the battery holder and two diodes present.



```
KKKK 04B 04B 04B 04B
KKKK 04B 04B 04B 04B
KKKK 04B 04B 04B 04B
KKKK 04B 04B 04B 04B
K    04B
  1,200 8N1 HI HEX
UART   3.2V   9
```

Screen 17: the Serial Decoder also offers a hexadecimal mode, useful for seeing binary data and control codes. Framing or parity errors are shown, which can help to determine the data format.

nine bits with no parity. These are shown as 8O, 8E, 8N or 9N and are followed by a choice of one or two stop bits.

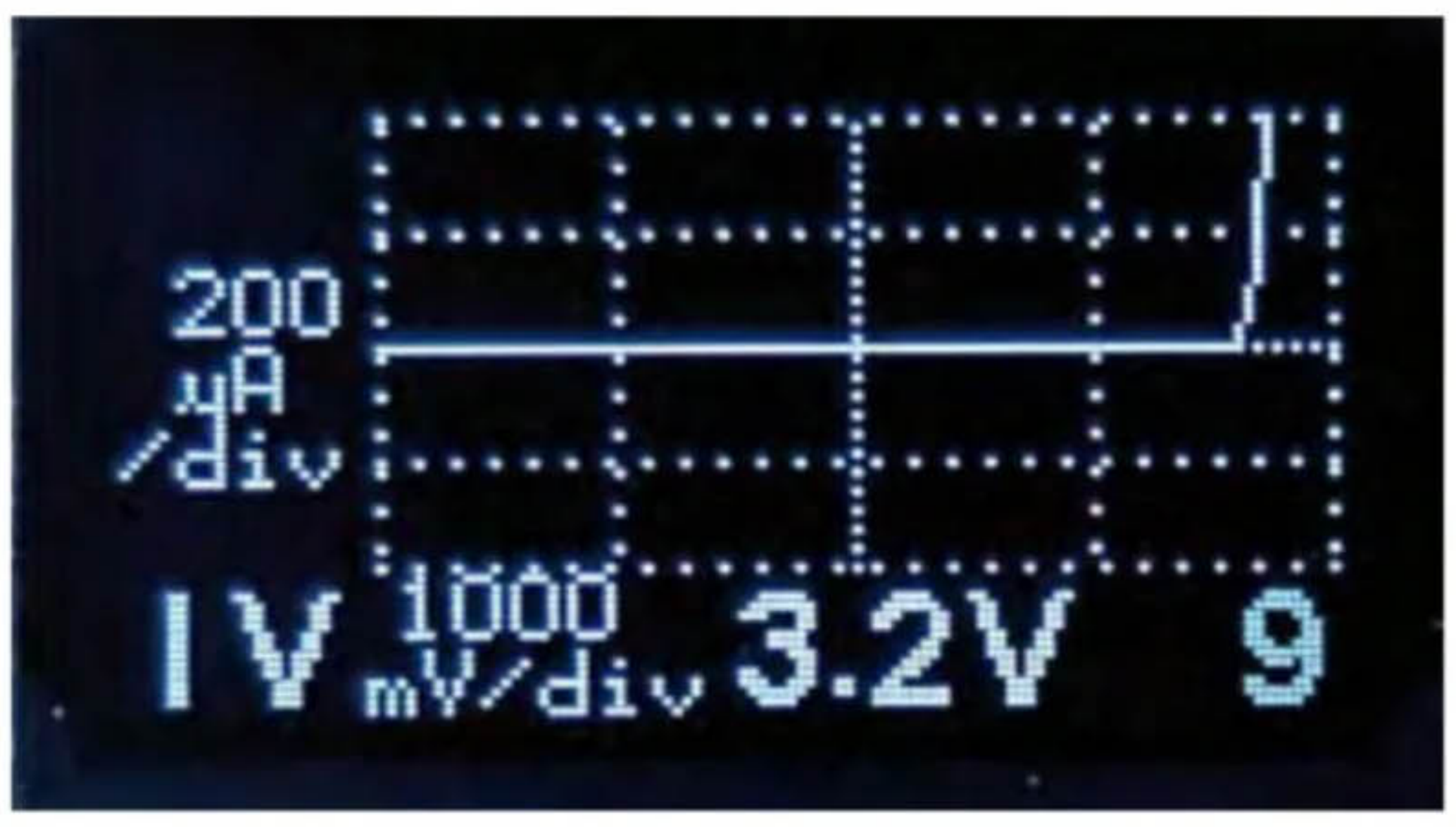
The idle logic level is next and can be HI or LO, followed by a choice of text or hexadecimal ('TXT' or 'HEX') display output.

Screen 16 shows TXT mode, which works much like a serial terminal and will handle line feed, carriage return and tab characters. The text will scroll up as lines are filled at the bottom of the screen. The text seen here is actually a decoded square wave; hence, the same character is repeated.

HEX mode does not handle any control characters but displays both ASCII and HEX representations, also scrolling up as needed. Only HEX mode can display the full range of 9-bit data, and it also indicates parity ('P') and framing ('F') errors. Screen 17 shows the same data as Screen 16 but in HEX mode.

The decoding depends on the PIC24FJ256GA702's hardware UART and logic levels, but since the I/O pins are behind the protective resistors, this will work fine with any logic levels of around 3V or higher. Even non-TTL voltage levels, such as legacy RS-232 (which can swing between –15V to +15V) should be successfully decoded by choosing a LO idle level, since –15V is the idle level.

#4 I/V plotter



Screen 18: while Diode mode cannot report dual diodes such as bicolour LEDs, the I/V Plotter shows both polarities. The current and voltage scales can be zoomed in for more detail.

Screen 18 shows the I/V (current vs voltage) plotter, designed to characterise passive components. This uses much the same scheme as Meter mode, applying a voltage via different resistor combinations to probe the component at different operating points.

Six readings are taken, including the voltage and current at each point. This is limited to about ±3V due to the cell supplying the test current; the current can be no more than around 1.5mA due to the minimum 2kΩ resistance.

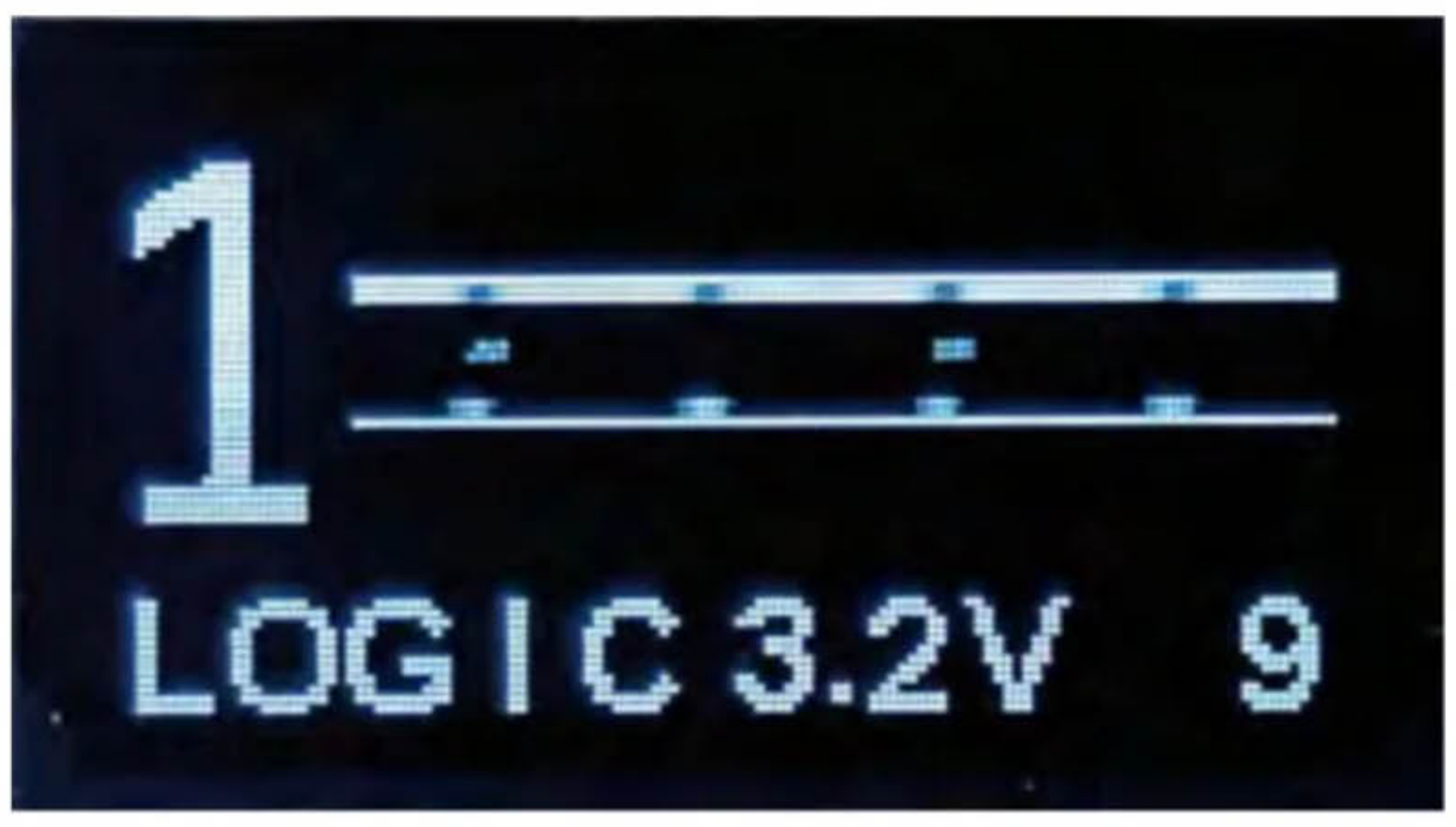
Like in Scope mode, the vertical and horizontal scales can be adjusted by using S1 to cycle between current (vertical), voltage (horizontal) and the timeout counter. S2 cycles between the available values.

The horizontal scale can be set to 1V, 0.5V, 0.25V, 0.1V or 0.05V per division, while the vertical scale can be 1mA, 500µA, 200µA, 100µA or 50µA per division. The corresponding scale values are displayed in mV and µA, respectively.

The 0V/0A origin is always at the centre of the display, and the I/V display updates continuously, so it is well-suited to sorting through piles of unmarked parts.

Screen 18 displays what what the *Advanced Tweezers* indicate for a yellow LED with a forward voltage of around 1.7V.

#5 Logic Analyser



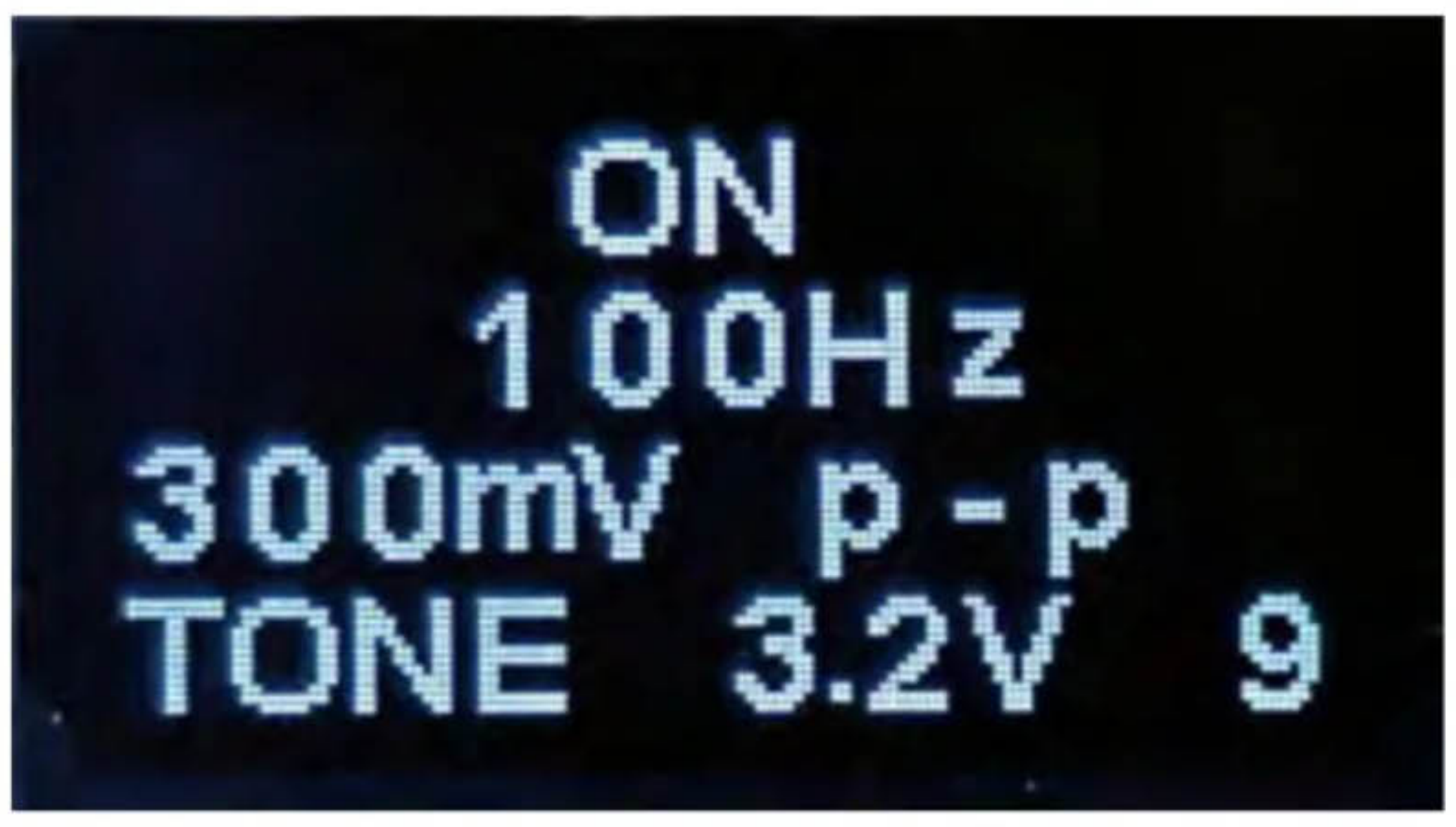
Screen 19: the Logic Analyser shows whether it detects a high, low or high impedance logic level. A scrolling chart also shows a brief history, making it easier to see transients and repeating patterns.

Pressing S3 again switches to the Logic Analyser, as shown in Screen 19. Sensing is done by alternately probing with high and low voltage levels via one of the 100kΩ resistors. A voltage that follows the probing voltage is assumed to be high impedance.

It shows 1, 0 or Z at the left of the screen to indicate a logical high, low or high-impedance level. A horizontal scrolling display also shows about one second's worth of history to allow brief transients or waveforms to be discerned.

Here, we see a high-level signal that is interrupted by brief low pulses. Like in the Scope and Meter modes, S1 and S2 will pause and resume the countdown timer, respectively.

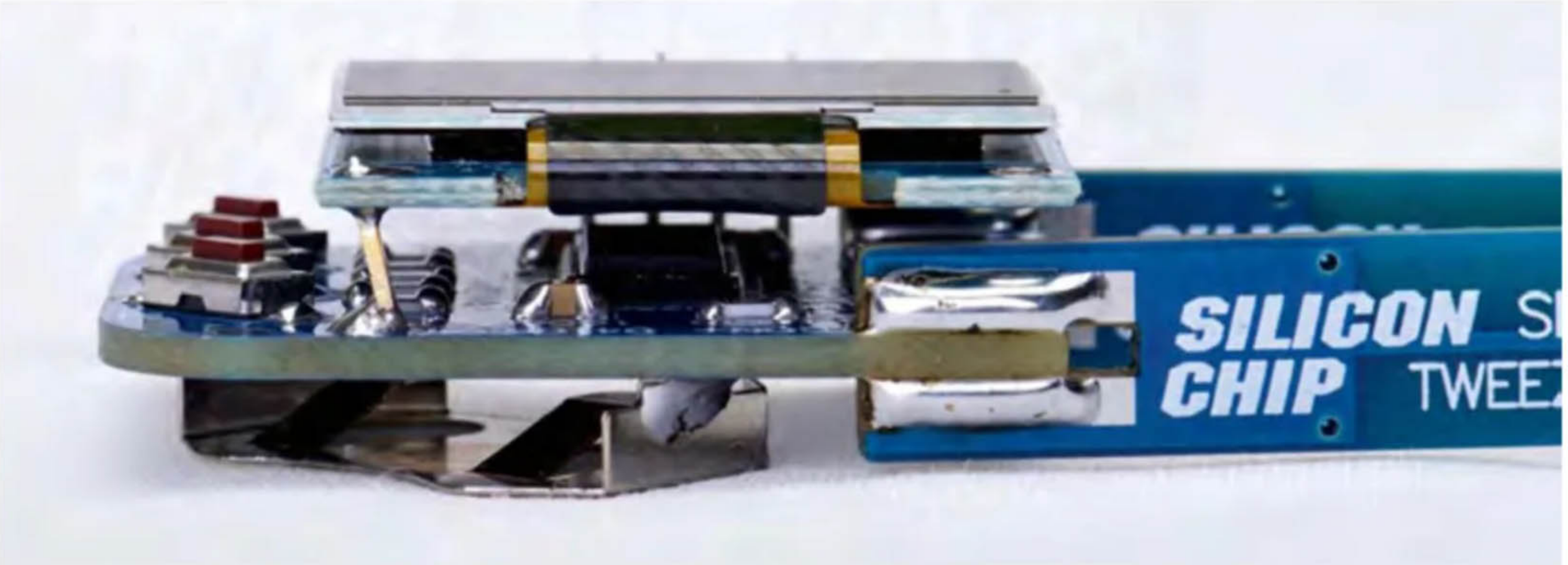
#6 Tone Generator



```
    ON
  100Hz
300mV p-p
TONE  3.2V  9
```

Screen 20: like Scope mode, the Tone Generator is handy at audio frequencies or as a simple clock generator. It can produce square waves at five different frequencies and four different amplitudes.

Screen 20 shows the Tone Generator. Unlike most of the other mode settings,



As shown last month, a header pin is used to act as a reinforcing spacer at one corner of the OLED. This prevents the assembly flexing and causing a short between the two PCBs.

which are retained between uses, the tone is turned off when it is not being used to avoid interfering with other modes. It can be toggled on and off by pressing S2 when the ON/OFF indicator is flashing.

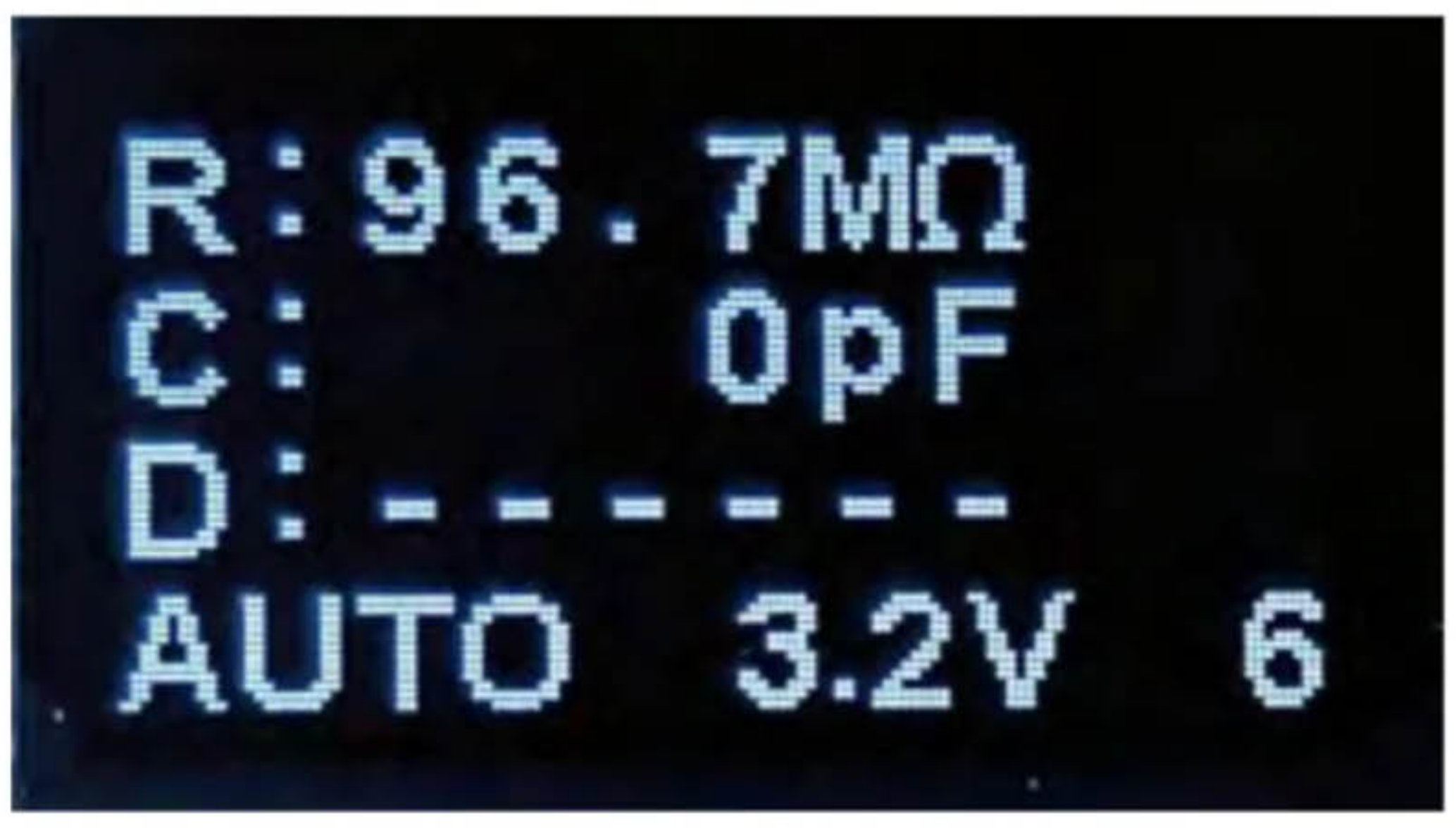
There are choices of 50Hz, 60Hz, 100Hz, 440Hz and 1kHz. Only square waves are produced. There are four output (peak-to-peak) levels, which are nominally 300mV, 600mV, 3V and 6V.

The 300mV waveform is produced by toggling one output via a 10kΩ resistor and dividing that with a 1kΩ resistor to ground. The 600mV selection drives two outputs similarly, but with opposing phases, to achieve the necessary swing.

The 3V and 6V outputs are fed to the tips directly from one or two pins respectively, without the divider. The level selections assume that the supply is at 3V and the load resistance is relatively high. Under other conditions, the voltages could be different.

Because of the way they are generated, the 300mV and 3V outputs also have a DC offset that the other two modes do not. So, you can use the 3V mode to drive a clock signal into 3.3V logic (or 5V logic, if it accepts a 3V signal swing), or you can use the 300mV and 3V modes to feed in an audio signal via a series capacitor (in the circuit, or added), which will remove the DC offset.

#7 Component measurements


R:96.7MΩ
C: 0pF
D:------
AUTO 3.2V 6

Screen 21: the Auto screen is only one of ten pages but encompasses and surpasses the abilities of its predecessors. It shows resistance, capacitance, diode polarity and forward voltage.

Finally, we come to the modes that can be used directly to read off the values of passive components. These are similar to the older *Tweezers* variants but have wider measurement ranges.

The Auto mode performs readings for resistors, capacitors and diodes, and displays the readings for all three. You might get readings for more than one component type, as there is no algorithm that will always correctly determine what has been connected.

Screen 21 shows Auto mode with no components connected. A high resistance and low capacitance are displayed. In Auto mode, pressing S1 will pause the countdown timer while S2 will resume it.

The subsequent Res, Cap and Diode modes concentrate on just the one component type and display it in a larger font. These are seen on Screens 22-24, respectively.

The maximum resistance that can be displayed depends mostly on leakage currents in the circuit. However, above 40MΩ, it will not achieve the stated 1% accuracy due to there being insufficient resolution at this end of the scale.

We have specified much the same range for capacitor testing as the *Improved Test Tweezers*. Above these ranges, leakage and other factors make it difficult to achieve the stated accuracy, especially for electrolytic capacitors.

The *Advanced Tweezers* will report up to 2000µF, but you should not rely on readings above 150µF. Since this is well above the typical range for the MLCC (multi-layer ceramic capacitor) types that we typically use for SMD designs, we don't expect this will be much of a concern.

Remember, many capacitors are manufactured to tolerances as wide as ±20% (sometimes even +80, –20%).

The diode test current is higher than the earlier *Tweezers* due to the 1kΩ test resistors. In the standalone diode mode, the forward test current (CON+ positive and CON− negative) is supplied between samples, so LEDs should be seen to light up when connected in the forward direction.

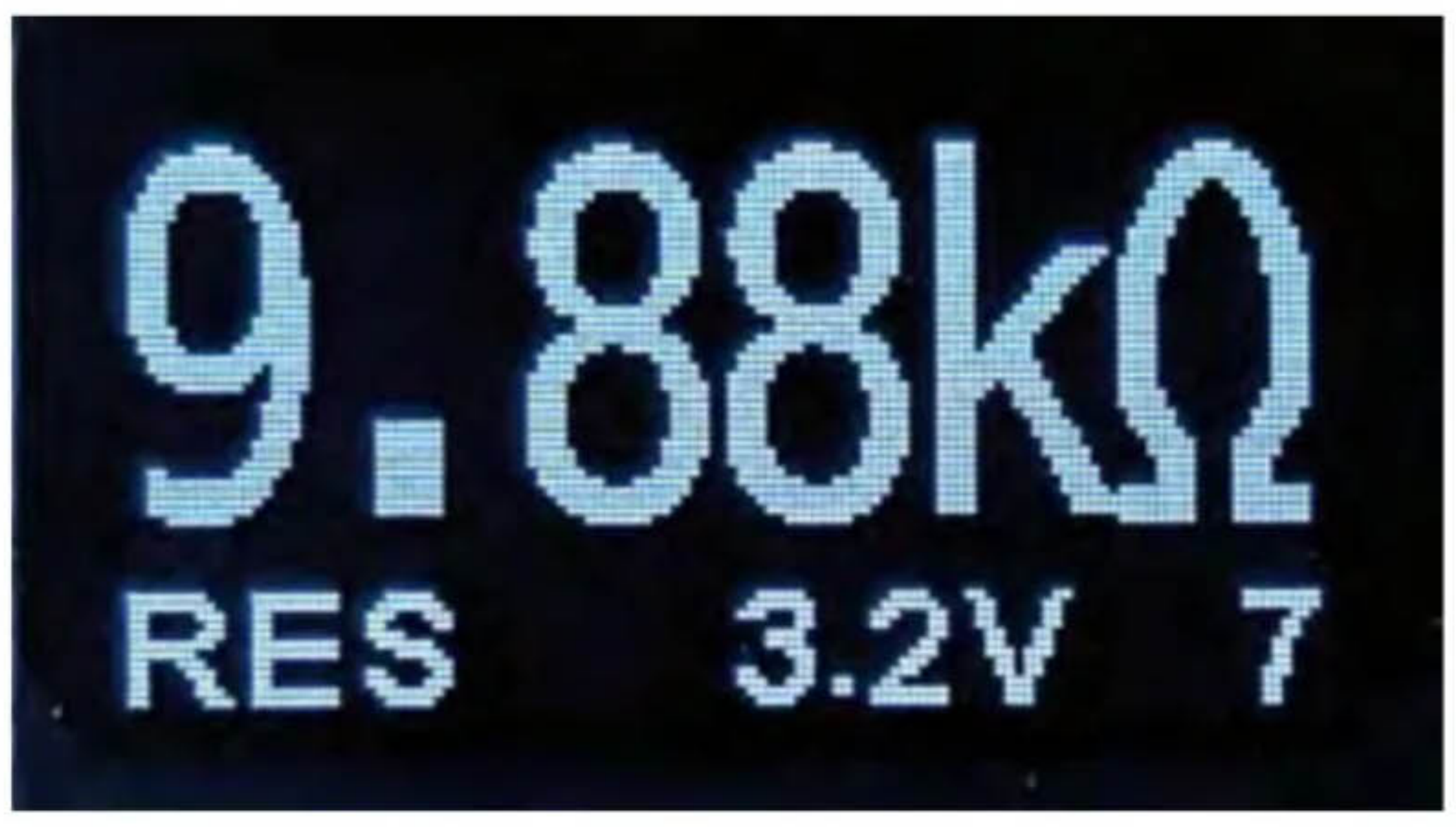
Conclusion

The original *SMD Test Tweezers* and the subsequent *Updated SMD Test Tweezers* are compact and handy devices. By adding a more powerful and better-provisioned microcontroller, we have added numerous extra features in creating the *Advanced SMD Test Tweezers*, including improved passive component measurement and many new modes.

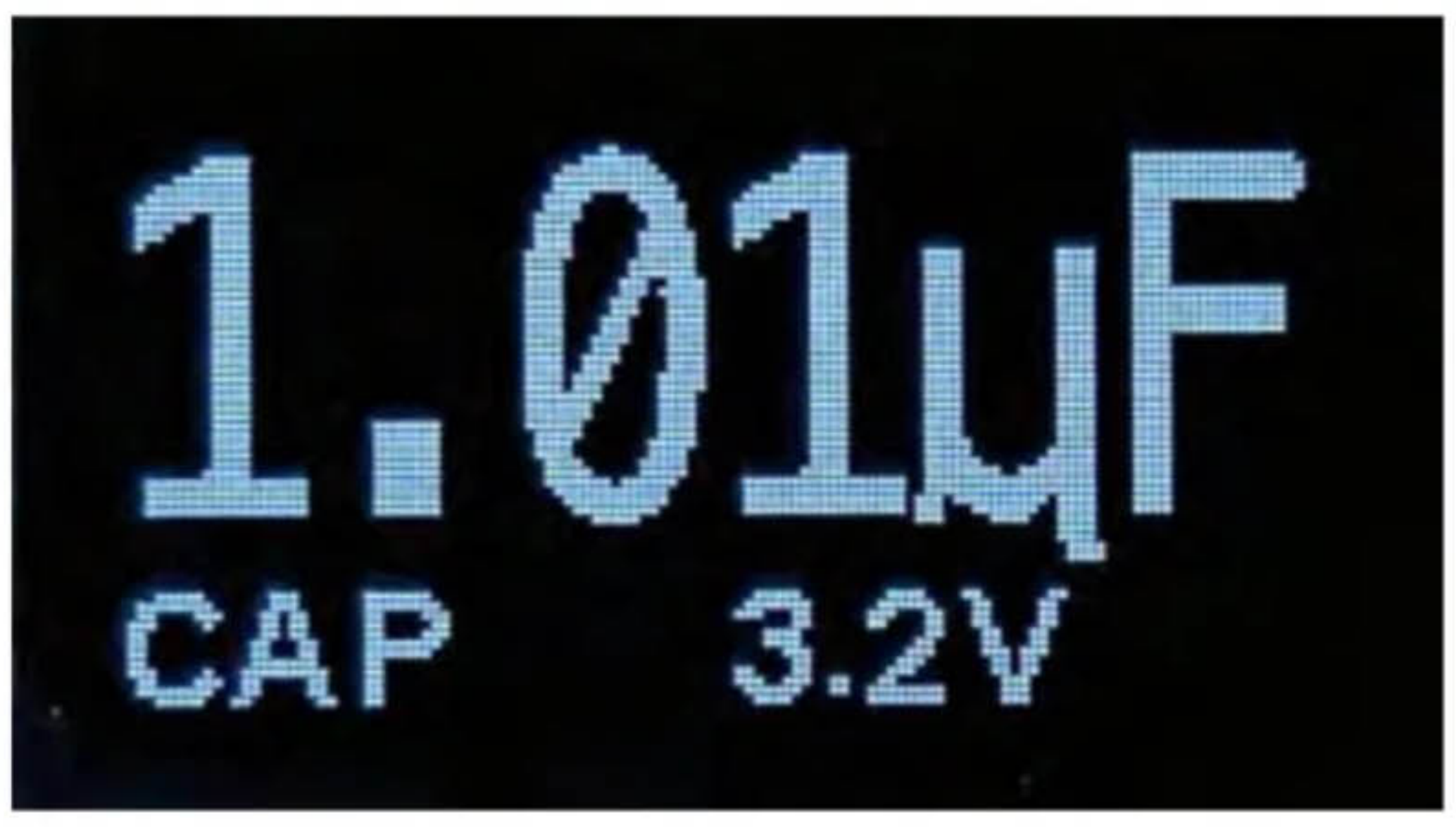
The PIC24FJ256GA702 is a substantial upgrade over the tiny 8-bit, 8-pin parts we previously used; we are not even using half of its resources or features in this design.

These new *Test Tweezers* can replace a basic voltmeter, logic probe and even oscilloscope in some situations, making them an indispensible general-purpose test instrument.

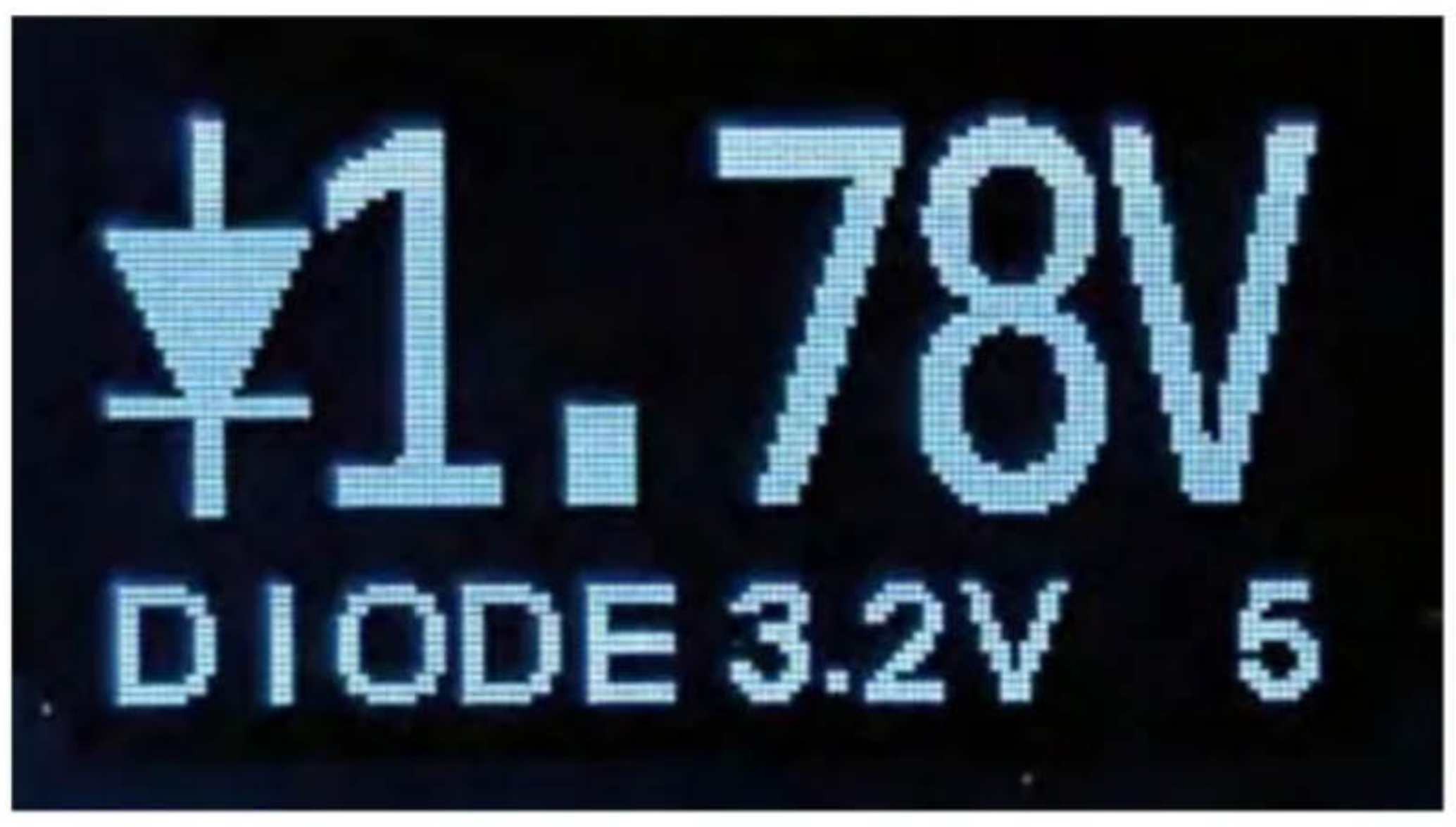
We expect that the *Advanced SMD Test Tweezers* will be both popular and useful, not just for the numerous test and measure modes, but also as a tool during SMD assembly.


9.88kΩ
RES 3.2V 7

Screen 22: the Res screen provides the same resistance information as the Auto screen but in a larger font, which is handy for checking and sorting through different resistor values.


1.01µF
CAP 3.2V

Screen 23: the Cap screen works similarly, displaying just the measured capacitance in large text. It's perfect for working out which part is which among a pile of unmarked SMD capacitors.


1.78V
DIODE 3.2V 5

Screen 24: the Diode screen is similar to the diode display on the Auto screen but a bias is applied from CON+ to CON− between tests. This lets you quickly check the polarity and operation of LEDs.

Active Mains Soft Starter

Part Two by John Clarke

Our *Active Mains Soft Starter*, introduced last month, is ideal for eliminating the switch-on kick from power tools rated up to 750W. You can also use it to avoid high inrush currents for stationary equipment that can trip circuit breakers or wear out switches. This article covers the assembly, testing, adjustment and calibration of this new *Soft Starter*.

The Active Mains Soft Starter uses a combination of an NTC thermistor and a MOSFET to provide an adjustable soft-starting period. Using a MOSFET means the thermistor experiences little heating, so repeated starts (within reason) do not degrade the effectiveness of the *Soft Starter*.

Both the MOSFET and the thermistor are bypassed by a relay after soft starting so that there is very little power loss or heating within the *Soft Starter,* even with a high load current draw. It is housed in a conveniently compact 17.1 × 12.1 × 5.5cm plastic enclosure with an IEC mains input socket, GPO/mains output and three (optional) neon indicators to show what it is doing.

Because it monitors the load current, it is automatically activated whenever the load appliance is switched on, even if the *Soft Starter* is already powered. That means you can use the trigger or switch on power tools to activate them. Or, you can simply switch it on at the wall, which is handy if you have multiple devices connected to the output (eg, via a power board).

Having described what it does and how it works, let's move on to building it.

Construction

Most of the parts mount on a double-sided, plated-through PCB coded 10110221 that measures 159 × 109mm and is avaiable form thr *PE PCB Service*. Once assembled, it is housed in a polycarbonate or ABS enclosure measuring 171 × 121 × 55mm. The only off-board parts are the IEC mains input socket, mains output socket and three neon indicators.

Fig.7 shows the parts layout on the PCB. Begin by installing the surface-mounting dual op amp (IC2). You will need a soldering iron with a fine tip (or a regular tip and some flux paste), a magnifier (if you do not have excellent vision) and good lighting.

Solder the IC to its PCB pads by first placing it with the pin 1 locating dot to the top left and aligning the IC leads to the corresponding pads. Then solder a corner pin and check that it is still aligned correctly. If it needs to be realigned, re-melt the soldered connection and gently nudge the IC into alignment.

When you're sure it's placed correctly, solder all the IC pins. Any solder that runs between and bridges two pins can be removed with solder wicking braid (adding extra flux paste is recommended). Note that pins 6 and

Warning: Mains Voltage

The entire circuit of the Active Soft Starter floats at mains potential and could be lethal should you make contact with it. Don't assume that because we use isolation between different parts of the circuit that some parts are safe to touch – they are not! The isolation between parts of the circuit is to allow for the differing voltage potentials in parts of the circuit rather than for safety.

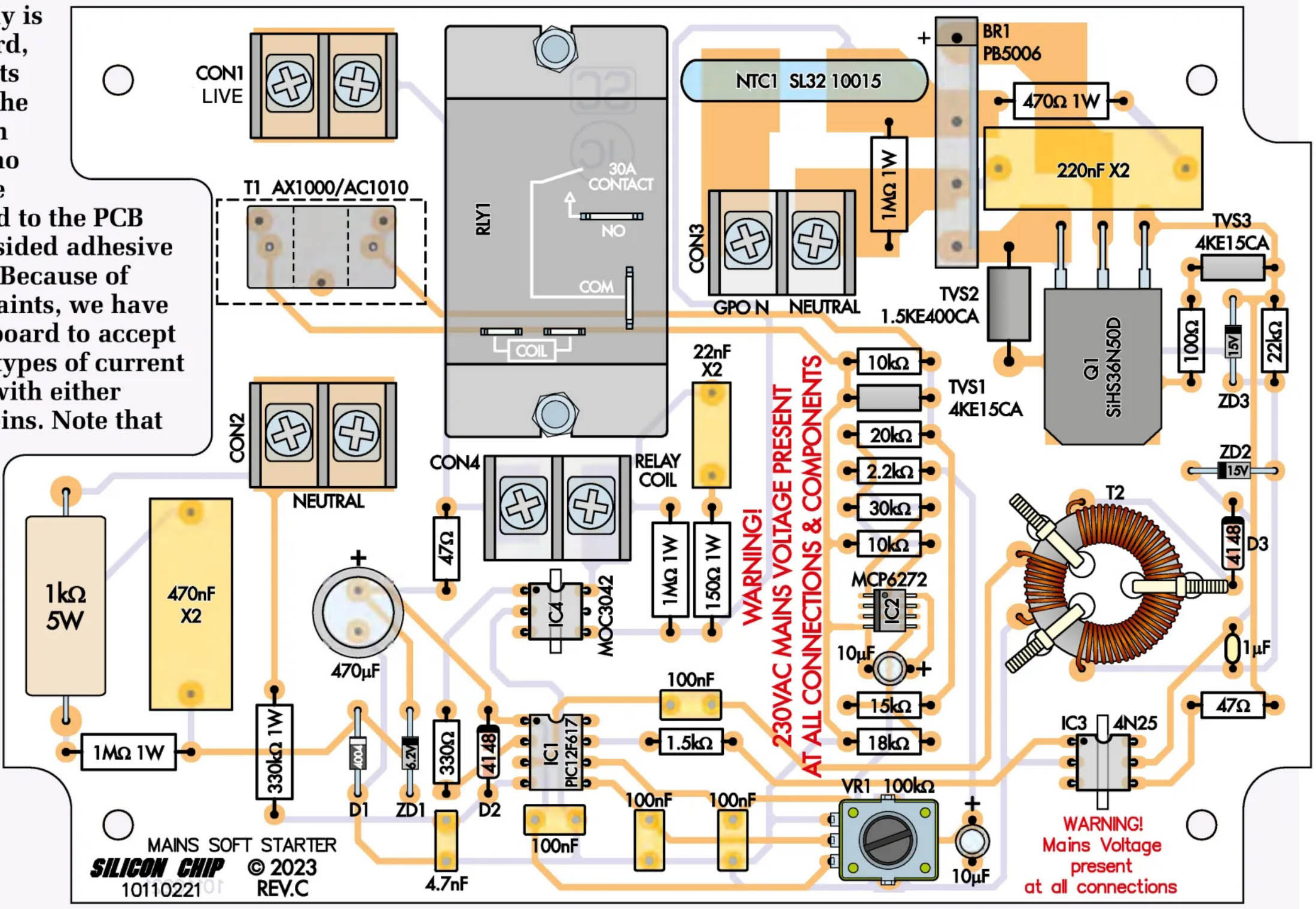

CON1
LIVE
T1 AX1000/AC1010
RLY1
30A CONTACT
NO
COM
COIL
NTC1 SL32 10015
BR1
PB5006
+
470Ω 1W
1MΩ 1W
220nF X2
CON3
GPO N
NEUTRAL
TVS2
1.5KE400CA
TVS3
4KE15CA
Q1
SiHS36N50D
100Ω
22kΩ
ZD3
ZD2
15V
CON2
NEUTRAL
CON4
RELAY COIL
22nF X2
10kΩ
TVS1
4KE15CA
20kΩ
2.2kΩ
30kΩ
10kΩ
MCP6272
IC2
T2
D3
4148
1μF
47Ω
1kΩ 5W
470nF X2
47Ω
IC4
MOC3042
1MΩ 1W
150Ω 1W
WARNING! 230VAC MAINS VOLTAGE PRESENT AT ALL CONNECTIONS & COMPONENTS
470μF
10μF
15kΩ
18kΩ
100nF
1.5kΩ
IC3
4N25
1MΩ 1W
330kΩ 1W
4004
D1
6.2V
ZD1
330Ω
4148
D2
IC1
PIC12F617
100nF
100nF
VR1 100kΩ
10μF
WARNING! Mains Voltage present at all connections
MAINS SOFT STARTER
SILICON CHIP © 2023
10110221
REV.C
4.7nF
100nF

Fig.7: assembly is straightforward, with most parts mounting on the PCB, as shown here. Q1 has no mounting hole and is adhered to the PCB using double-sided adhesive thermal tape. Because of supply constraints, we have designed the board to accept two different types of current transformer, with either two or three pins. Note that the three TVSs are bidirectional, so their orientations are not critical.

7 are joined on the PCB, so a bridge between them won't matter.

Fit the resistors next. Table 1 shows their colour-code values, but we recommend using a digital multimeter (DMM) to check each resistor before soldering it in place. Three resistor types are used; one is a 1kΩ 5W wirewound, six are 1W types, and the remainder are smaller ½W resistors. Mount the 5W resistor with a gap of about 1mm from the PCB to allow air to circulate.

Diodes D1-D3 and zener diodes ZD1-ZD3 are next on the list. Ensure they are oriented correctly and the types are not mixed up before soldering their leads.

TVS1-TVS3 can also be installed now. These are bi-directional (AC) devices, so they can be installed either way around on the PCB. Make sure the correct type number for each TVS is inserted in the specified location.

Mount the remaining ICs, taking care to get the correct IC in each place and with the proper orientation. We used a socket for IC1, although you could solder it directly to the PCB, assuming it has already been programmed. IC3 and IC4 both have six pins, so don't get them mixed up. On the PCB, pin 5 of IC4 has only a tiny pad to provide an increased creepage distance between pins 4 and 6.

You can fit the capacitors next, of which there are four types: the mains X2-rated capacitors, electrolytic capacitors, MKT polyester and a multi-layer ceramic. Note that the electrolytic capacitors need to be oriented correctly since they are polarised, while the others can be installed either way around.

Remember that the 100nF capacitors could be labelled as 104 (10pF × 10^4), while the 4.7nF capacitor could be labelled 472 (47pF × 10^2) and the 1μF ceramic capacitor could be labelled as 105 (10pF × 10^5).

Next, install potentiometer VR1 and thermistor NTC1. Bridge rectifier BR1 is next; its positive lead is spaced wider than the remaining leads, so it will only fit in one way.

MOSFET Q1 can also be fitted now. Bend its leads by 90° about 5mm from the package and secure the metal tab to the PCB using some double-sided thermal transfer tape before soldering the leads. Because the tracks are thin near the pads for the MOSFET leads, build up their exposed copper tracks on the underside of the PCB with solder.

Install CON1 to CON4 next, as well as the current transformer (T1). Depending on which type of transformer you have, it might have two or three leads. The PCB will accommodate either type.

The next step is to install relay RLY1 with its coil terminals toward CON4. The relay is secured using 15mm-long M3 screws and nuts, with each screw inserted from the underside of the PCB.

Winding transformer T2

The windings on the toroidal ferrite core for T2 are made with 0.25mm-diameter enamelled copper wire, as shown in Fig.8. The primary has 10 turns, while the secondary has 48 turns. Cut a 125mm length for the primary and 1m for the secondary, and wind on each side-by-side; the winding directions are unimportant. The windings must be separated by at least 3mm at each end.

Mount the finished transformer on the PCB with two cable ties that both secure the toroid and keep the primary and secondary windings separated, so make sure they go between the windings. The third cable tie holds down the toroid in the middle of the secondary winding – see Fig.7 above.

Pass the primary and secondary wires through the PCB pads and strip off the

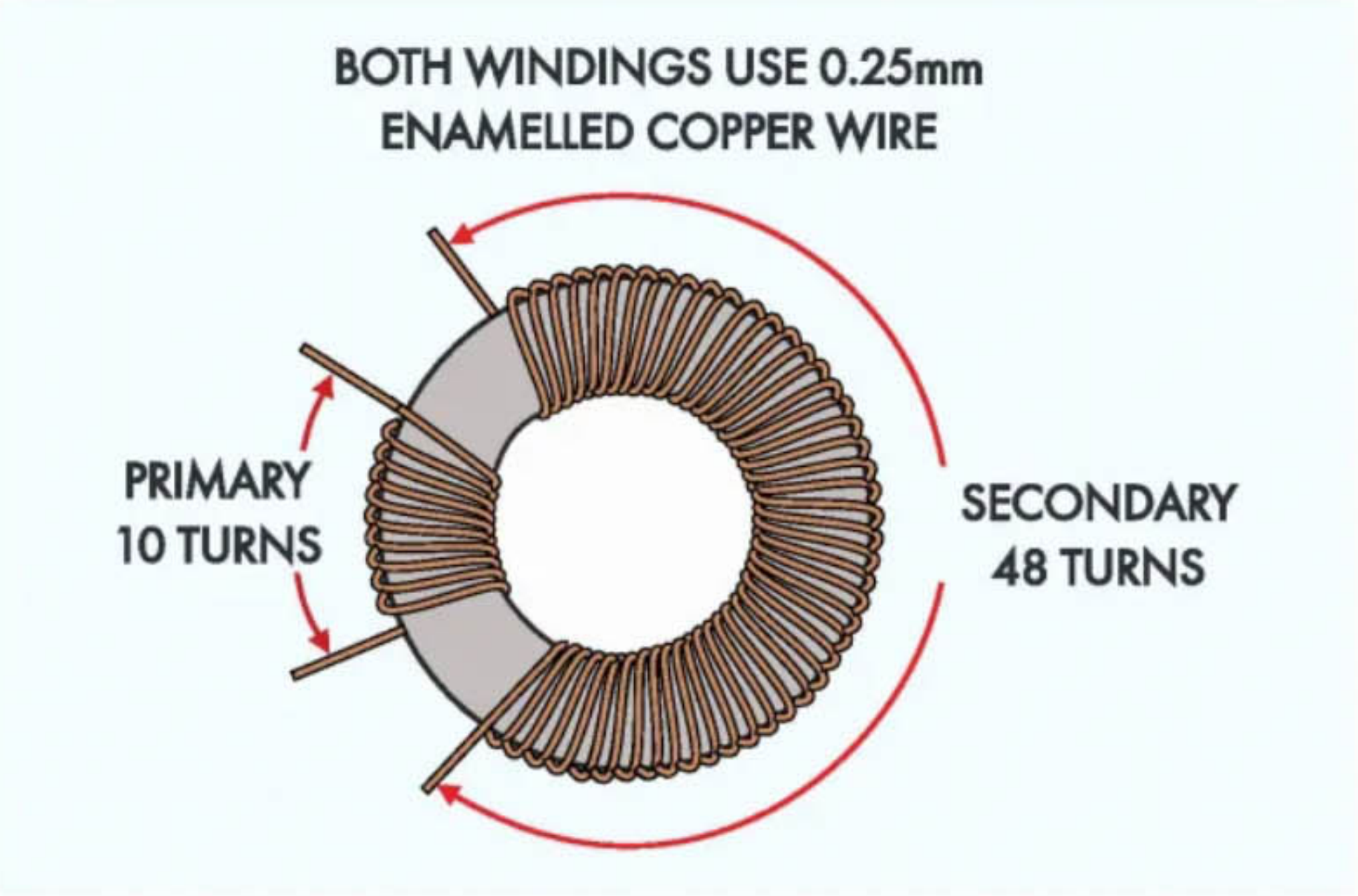

BOTH WINDINGS USE 0.25mm ENAMELLED COPPER WIRE
PRIMARY 10 TURNS
SECONDARY 48 TURNS

Fig.8: wind T2 as shown here, keeping the windings neat and close together and ensuring at least 3mm of separation between the primary and secondary at either end.

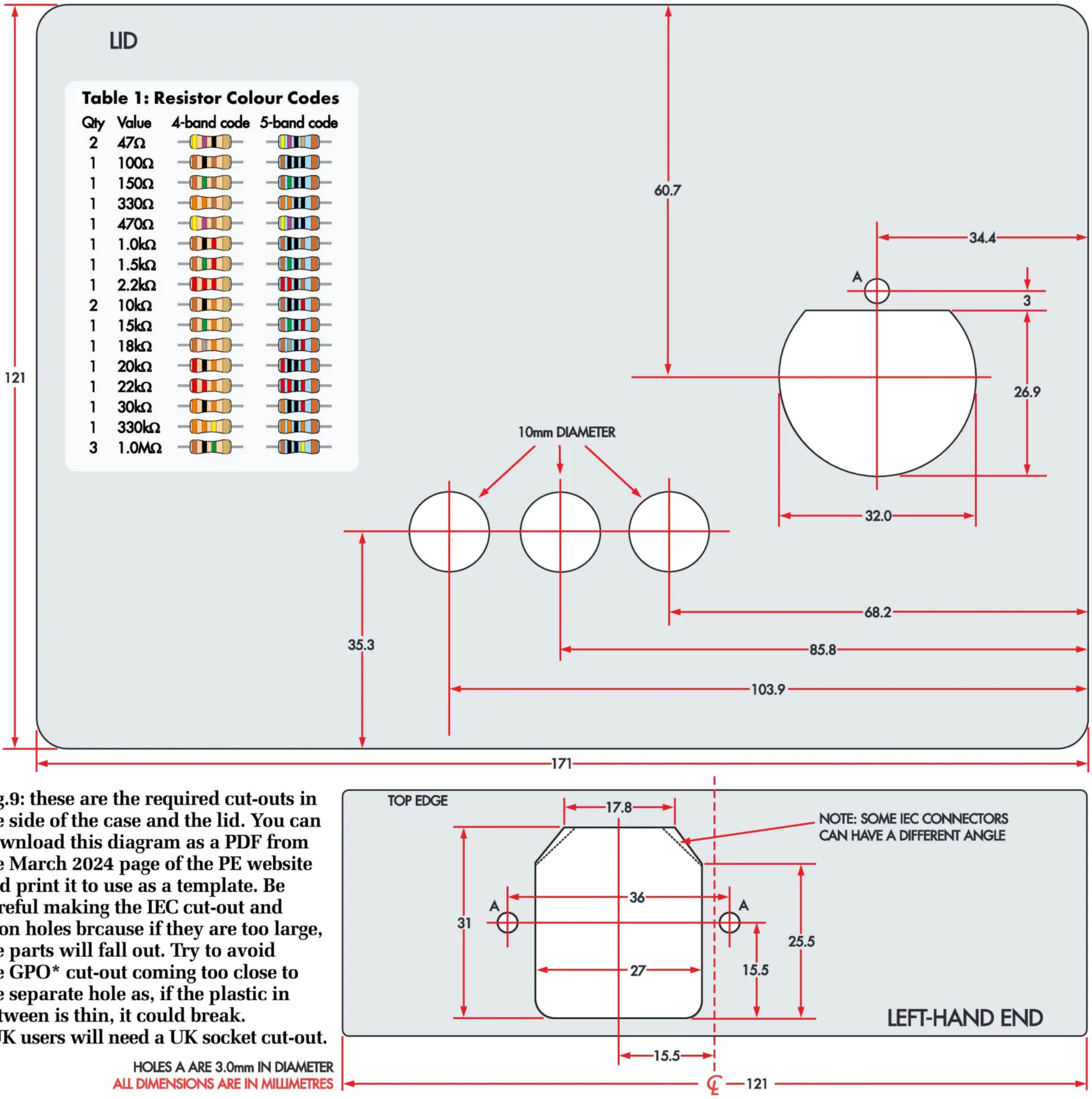

LID
60.7
34.4
A
3
26.9
121
10mm DIAMETER
32.0
68.2
85.8
103.9
35.3
171
TOP EDGE
17.8
NOTE: SOME IEC CONNECTORS CAN HAVE A DIFFERENT ANGLE
36
A
A
31
25.5
15.5
27
LEFT-HAND END
15.5
121
HOLES A ARE 3.0mm IN DIAMETER
ALL DIMENSIONS ARE IN MILLIMETRES

Table 1: Resistor Colour Codes

Qty	Value	4-band code	5-band code
2	47Ω		
1	100Ω		
1	150Ω		
1	330Ω		
1	470Ω		
1	1.0kΩ		
1	1.5kΩ		
1	2.2kΩ		
2	10kΩ		
1	15kΩ		
1	18kΩ		
1	20kΩ		
1	22kΩ		
1	30kΩ		
1	330kΩ		
3	1.0MΩ		

Fig.9: these are the required cut-outs in the side of the case and the lid. You can download this diagram as a PDF from the March 2024 page of the PE website and print it to use as a template. Be careful making the IEC cut-out and neon holes brcause if they are too large, the parts will fall out. Try to avoid the GPO* cut-out coming too close to the separate hole as, if the plastic in between is thin, it could break.
***UK users will need a UK socket cut-out.**

insulation at all four ends to allow the wires to be soldered. The insulation can be burnt off with a hot soldering iron, by holding a blob of hot solder over the wire ends for a few seconds. Otherwise, you can scrape the insulation off with a sharp hobby or craft knife.

Final assembly

The *Soft Starter* PCB is secured to the base of the enclosure using 6mm-long M3 machine screws that screw into the integral brass inserts. But before attaching the PCB, the IEC connector cut-out will need to be made in the side of the enclosure. You will also need to drill holes in the lid for the GPO/mains socket and neon indicators.

Fig.9 is a template for the required cut-outs. You can photocopy it from the magazine at 1:1 scale or download a PDF from the March 2024 page of the PE website and print it out (make sure to print it at 'actual size') – see: **https://bit.ly/pe-downloads**

The large cut-outs for the mains GPO/mains socket and IEC connector can be made by drilling a series of small holes around the inside perimeter, knocking out the centre piece and filing the outline to a smooth finish.

If you use Jaycar neon indicators, the holes must be sized so that they stay clipped in place when inserted into the cut-out. So take care with the hole size; the inside of the hole will need a slight chamfer to reduce the panel thickness so that the clips can spring outward to secure each neon. The Altronics neon indicators are secured with a nut threaded onto the plastic housing instead of clips.

Once the drilling and filing are complete, install the IEC connector. The PCB can then be placed inside the case, but don't secure it just yet.

First, the IEC connector must be secured using countersunk nylon M3 × 10mm screws, although you can use metal nuts. You may need to cut away some of the internal ribs in the case to allow the nuts to fit as we had to for the prototype (you can just see this in the photo overleaf).

The nylon screws are essential as they avoid the possibility of the screws becoming live (at mains voltage) should a mains wire inside the enclosure come adrift and contact a screw holding the IEC connector.

Before attaching the mains/GPO socket and neon indicators, you can print out the front panel label shown in Fig.10. You can also download it as a PDF from from the March 2024 page of the PE website.

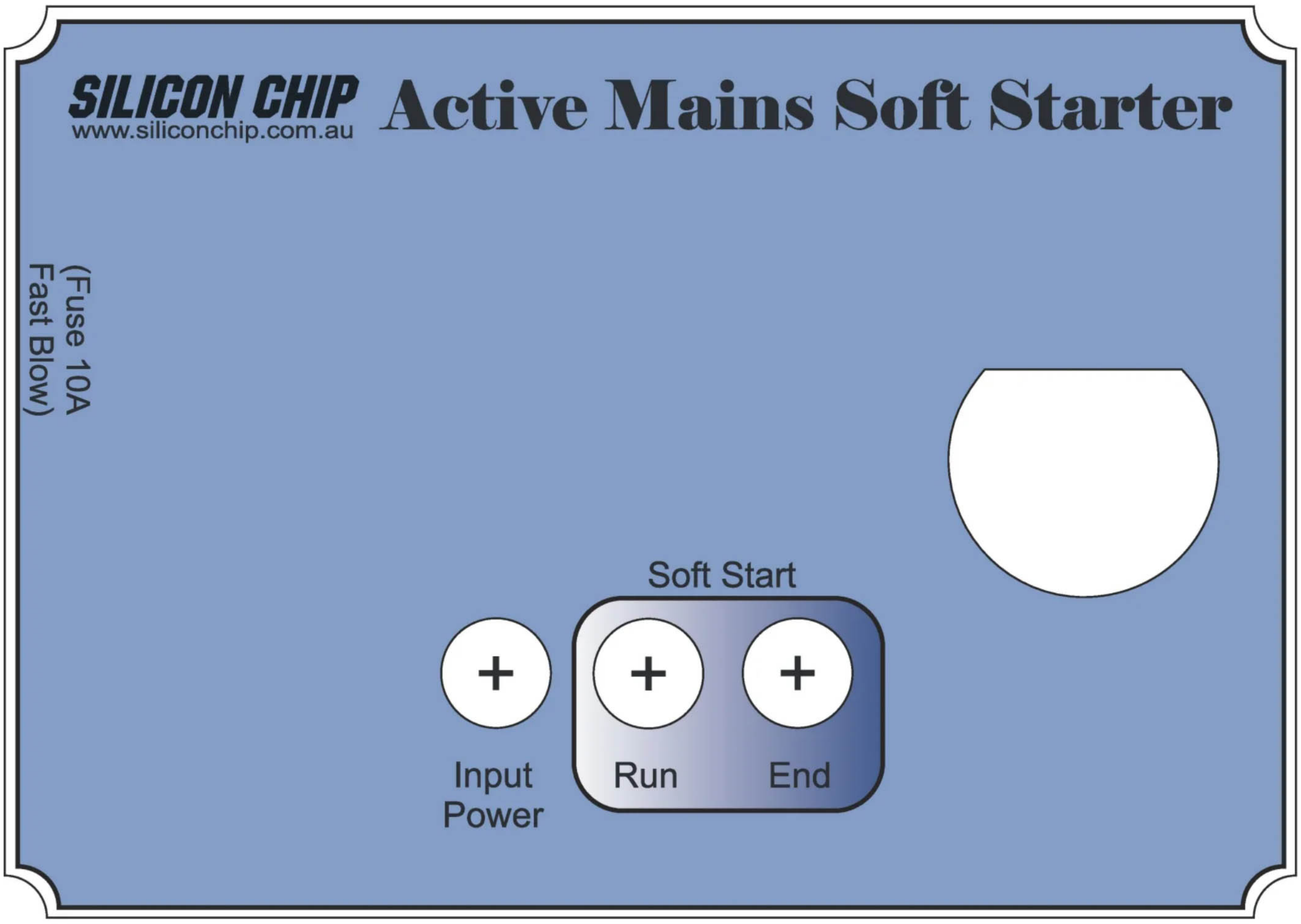


Fig.10: there are two different versions of the front panel artwork that you can download, either with the neon holes marked (as shown here) or without, if you'd prefer not to fit them.

The download includes two versions of the front panel. One does not have the three neon indicator holes, and is included if you prefer not to use them. The wiring is also simplified when not using neon indicators.

All wiring must be run as shown in Fig.11, using mains-rated cable. Be sure to use 10A cable for the thicker wires shown in Fig.11; brown wire must be used for the live wiring while the blue wire is used for neutral. Green/yellow-striped wire is used for the earth wiring only, and the earth lead from the IEC socket must go straight to the GPO/mains outlet.

The thinner wires shown (without a red asterisk) can use lighter-duty 7.5A mains wire, or simply 10A wiring throughout if you prefer.

Be sure to insulate all the connections with heatshrink tubing for safety and cable tie the wires as shown, to prevent any wire breakages coming adrift. Use 10mm-diameter heatshrink around the bodies of the neon indicators, 5mm for the wires to the IEC connector (red or brown for live, blue or black for neutral, and green for Earth) and 3mm for the wires to the relay (similar colour coding).

Note how the relay contact connections are made using 4.8mm spade crimp lugs while the relay coil wires are soldered. Try to avoid melting the surrounding relay plastic housing while doing that, and be sure to insulate the joints afterwards with heatshrink tubing. The wires to the IEC socket are also soldered and then insulated.

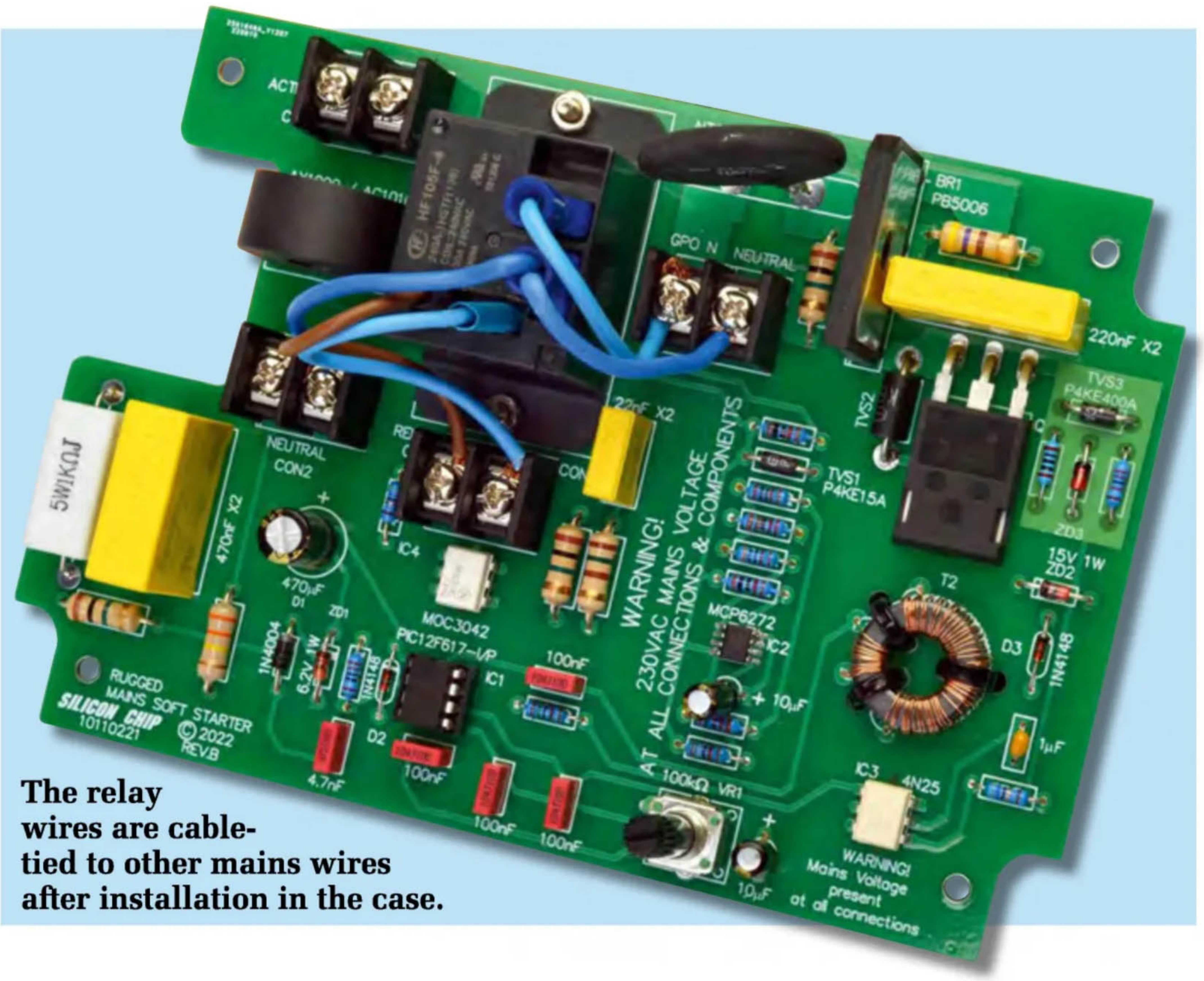
Secure the live and neutral leads to the GPO/mains outlet using cable ties that pass through the holes in its moulding. Also, use neutral-cure silicone (eg, roof and gutter silicone) to cover the live bus piece that connects the live pin to the fuse at the rear of the IEC connector as it is live, and there is no good reason for it to be exposed.

Take great care when making the connections to the mains socket (GPO). In particular, be sure to run the leads to their correct terminals (the GPO/mains socket has the L, N and E clearly labelled) and do the screws up tightly so that the leads are held securely. Similarly, ensure that the wires to the screw terminals are firmly secured.

Testing

Always attach the lid using at least two screws at diagonal locations before switching on the power.

Before applying power, check your wiring carefully and ensure all mains connections are covered in heatshrink tubing, and the wiring is cable tied. Then install the 10A fuse inside the fuse holder and verify that IC1 is plugged into its socket and correctly oriented.



The relay wires are cable-tied to other mains wires after installation in the case.

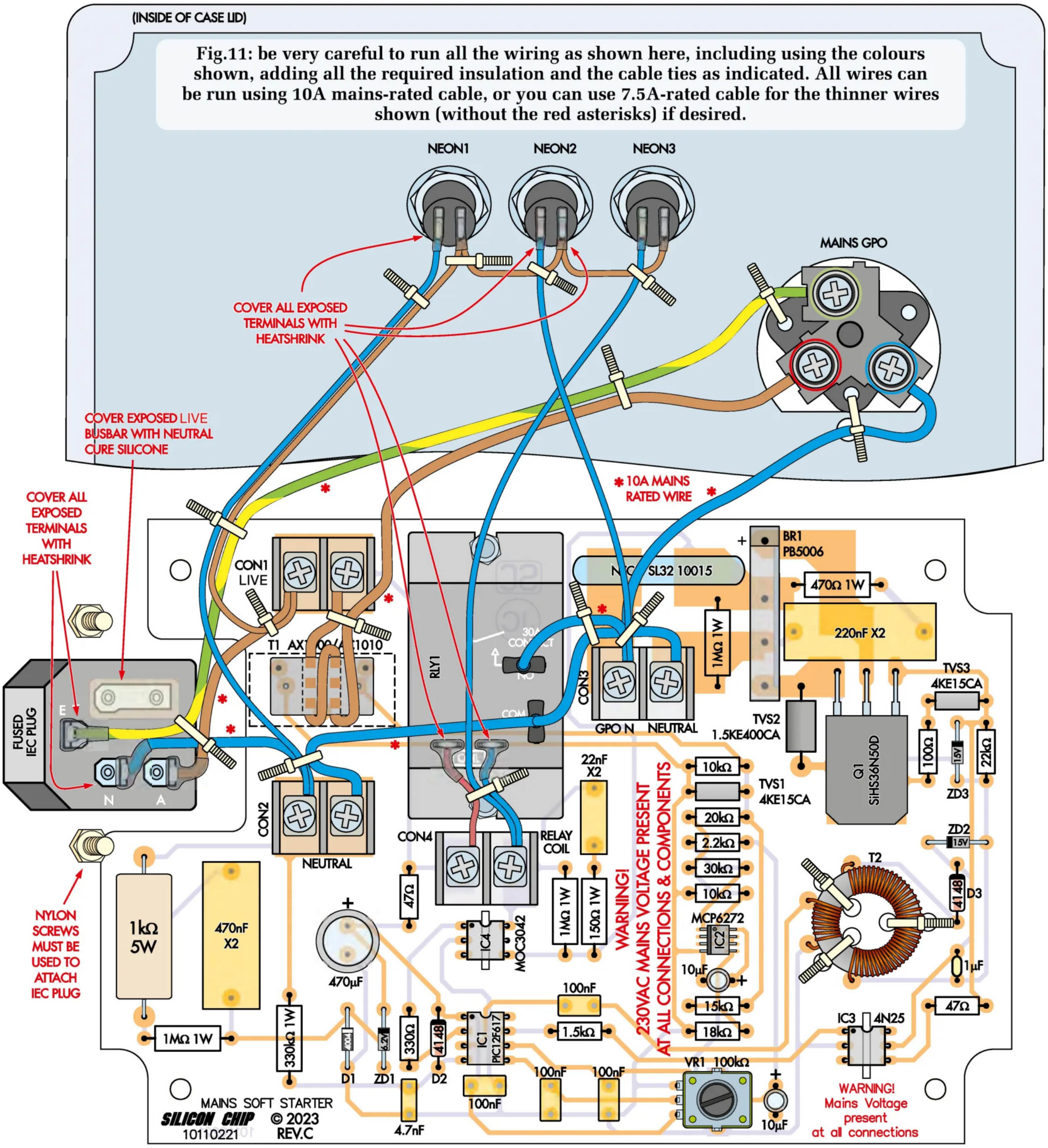


Fig.11: be very careful to run all the wiring as shown here, including using the colours shown, adding all the required insulation and the cable ties as indicated. All wires can be run using 10A mains-rated cable, or you can use 7.5A-rated cable for the thinner wires shown (without the red asterisks) if desired.

(INSIDE OF CASE LID)
NEON1
NEON2
NEON3
MAINS GPO
COVER ALL EXPOSED TERMINALS WITH HEATSHRINK
COVER EXPOSED LIVE BUSBAR WITH NEUTRAL CURE SILICONE
COVER ALL EXPOSED TERMINALS WITH HEATSHRINK
* 10A MAINS RATED WIRE
FUSED IEC PLUG
E
N
A
NYLON SCREWS MUST BE USED TO ATTACH IEC PLUG
CON1 LIVE
T1 AX1600/AC1010
RLY1
30A CONTACT
NO
COM
COIL
CON2
NEUTRAL
CON4
RELAY COIL
CON3
GPO N
NEUTRAL
NTC SL32 10015
BR1 PB5006
470Ω 1W
1MΩ 1W
220nF X2
TVS2 1.5KE400CA
TVS3 4KE15CA
Q1 SiHS36N50D
100Ω
15V
22kΩ
ZD3
ZD2
15V
D3
4148
T2
1μF
47Ω
IC3 4N25
WARNING! Mains Voltage present at all connections
22nF X2
1MΩ 1W
150Ω 1W
WARNING! 230VAC MAINS VOLTAGE PRESENT AT ALL CONNECTIONS & COMPONENTS
10kΩ
TVS1 4KE15CA
20kΩ
2.2kΩ
30kΩ
10kΩ
MCP6272
IC2
10μF
15kΩ
18kΩ
VR1 100kΩ
10μF
47Ω
IC4 MOC3042
1kΩ 5W
470nF X2
470μF
1MΩ 1W
330kΩ 1W
D1
4004
ZD1
6.2V
330Ω
D2
4148
IC1 PIC12F617
100nF
1.5kΩ
100nF
100nF
100nF
4.7nF
MAINS SOFT STARTER
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10110221 REV.C

Should you forget to install IC1 before powering up, the 4.7nF capacitor at the pin 4 connection could be left with a remnant voltage when you switch off the power. This can destroy IC1 when it is plugged in. So if you power it up without IC1 plugged in, wait for a few minutes with power off and check that the voltage between pins 4 and 8 is less than 1V before plugging in the IC.

Typically, VR1 would be set to mid-travel for a nominal one-second soft-start period. If set full anti-clockwise, VR1 gives a 9.5s soft-start period while near full-clockwise gives a half-second soft start period.

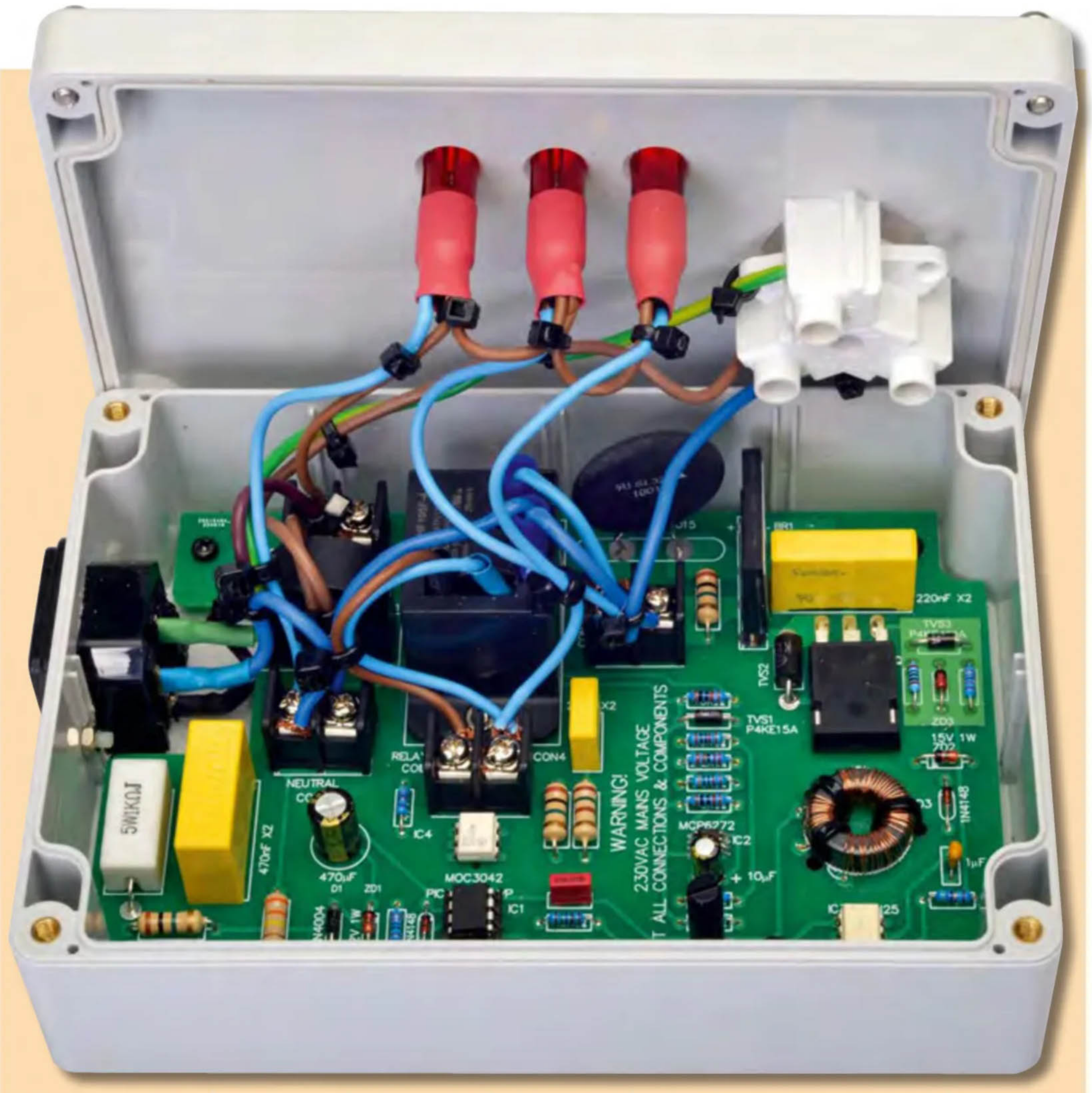
Calibration

Rotating VR1 fully clockwise has the *Soft Starter* enter another mode. This is used to measure the voltage from the precision rectifier when no appliance is connected. This is the offset voltage that needs to be taken into consideration when detecting whether there is current flow or not when an appliance is detected.

Typically, the output of IC2a (the full-wave rectified current waveform) will not sit at the negative supply at pin 4 with no load, but will be slightly positive. This offset can be measured and taken into account by IC1. This setting only needs to be done if the soft start circuit does not correctly detect when the appliance is off.

To set this offset, with the power off and unplugged from the wall, rotate VR1 fully clockwise. No appliance should be plugged into the *Soft Starter's* mains/GPO outlet. Attach the lid, power it up and wait a few seconds before switching it off. This will let it store the DC voltage produced by IC2 when no current is measured.

Unplug it, remove the lid and rotate VR1 back from fully clockwise to the desired soft-start period. As mentioned earlier, somewhere mid-way will give a suitable soft-start duration of one or two seconds for most



The completed unit just before the lid is attached. The numerous cable ties mean that even if a wire breaks off, it can't make contact and damage other parts of the circuit or create a shock hazard.

situations. However, other periods are available depending on your appliance's requirements.

Choosing the soft-start period

The available periods are 9.5, 5.5, 2.0, 1.0, 0.625 or 0.5 seconds, adjusted using VR1. You can use the slower rates for soft-starting capacitive loads if you are not concerned about how long it will take to power up the load. The 9.5s startup period is probably too long for most cases, but a 5.5s period is a good option.

For power tools, the best period depends on the time the tool takes to get up to full speed and the acceptable amount of movement the tool makes during starting. A shorter duration will produce more tool movement than a longer duration, but will let you get to work faster. If the period is longer than necessary, you will need to wait longer for the tool to be ready to use.

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Input Power
Run
End

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Teach-In 2024

ESP-WROOM-32
EN
BOOT
VIN GND D13 D12 D14 D27 D26 D25 D33 D32 D35 D34 VN VP EN
3V3 GND D15 D2 D4 RX2 TX2 D5 D18 D19 D21 RX0 TX0 D22 D23

Learn electronics with the ESP32

by Mike Tooley

Part 1 – Getting started

Welcome to Teach-In 2024! In this first article of the series, we will start with an overview of the ESP32 and how to use the development environment. We will move on to show you how to use your PC to monitor the ESP32's built-in capacitive touch sensors and our practical project involves using the ESP32 in a portable emergency beacon.

The learning objectives for this part are to know and understand:

- Installation and use of Arduino IDE
- How to enter and test code
- Use of a breadboard with the ESP32.

Why ESP32?

There are several good reasons why we've chosen the ESP32 as a platform for this series. Put simply, the ESP32 is well-established (launched in 2016), powerful and easy to use. The device is highly configurable and can be used in applications ranging from the most basic application – controlling an LED display – to the most demanding uses – MP3 streaming and decoding. The device offers extensive analogue and digital I/O, a serial UART, compatibility with popular and universal SPI and I^{2}C devices. It also has Ethernet, dual-mode Bluetooth, and Wi-Fi connectivity. At well under £10 for a development board (see Fig.1.1) that's really hard to beat!

A really handy plus point is that the ESP32 has excellent built-in RF technology. This avoids the tricky problem of having to add external RF components, which, because of the signal frequencies involved, can often be challenging and problematic in terms of circuit layout. The device incorporates an RF power amplifier (with an output of up to 20dBm), a low-noise receiver amplifier, an antenna switch and RF filters. That's a lot of tricky electronics avoided.

In recent years the feature rich ESP32 has become firmly established as the starting point for a wide range of low-cost control and IoT (Internet of Things) applications. The reasons for its success include, in no particular order:

Exceptional connectivity

The ESP32 boasts multiple connectivity options based on 2.4GHz Wi-Fi, Bluetooth

About Teach-In

Our latest *Teach-In* series is about using the popular ESP32 module as a basis for learning electronics and coding. We will be making no assumptions about your coding ability or your previous experience of electronics. If you know one but not the other, you have come to the right place. On the other hand, if you happen to be a complete newbie there's no need to worry because the series will take a progressive hands-on approach. There will be plenty of time to build up your knowledge and plenty of opportunity to test things out along the way.

We've not included too much basic theory because this can be easily found elsewhere, including several of our previous *Teach-In* series, see:

https://bit.ly/pe-ti
https://bit.ly/pe-ti-bundle

There will be projects and challenges to help you check and develop your understanding of the topics covered each month.

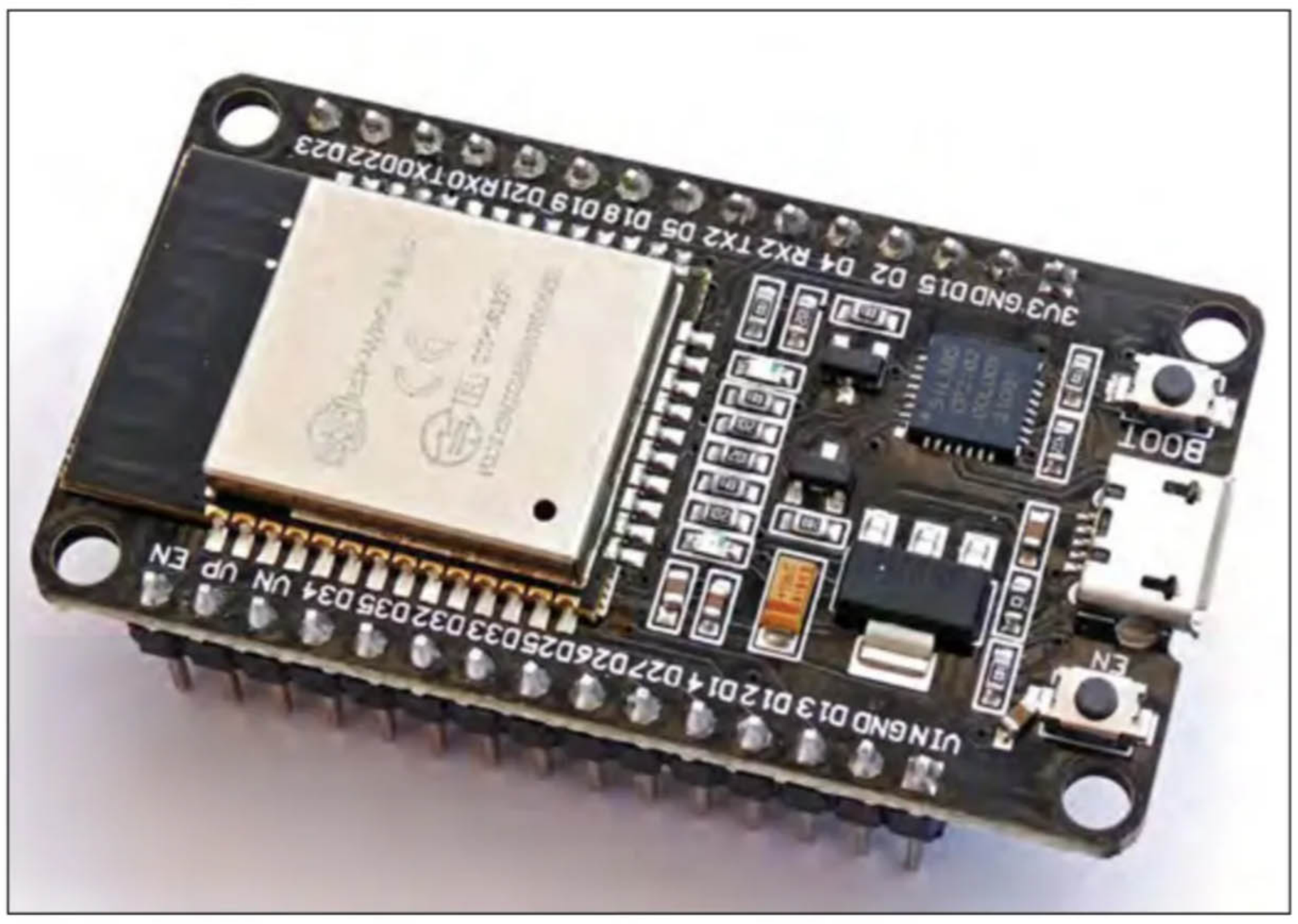


Fig.1.1. A low-cost ESP32 development board.

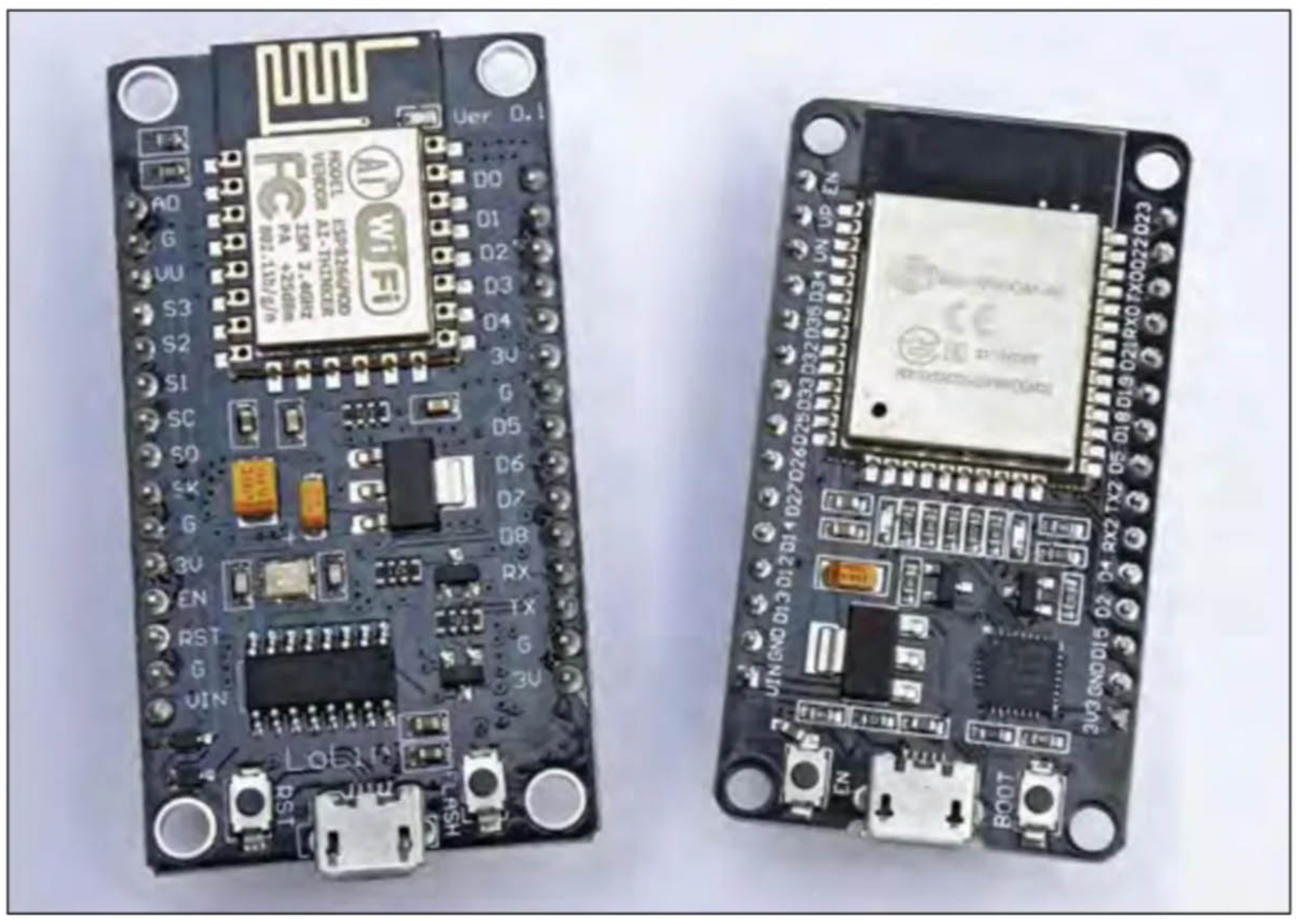


Fig.1.2. ESP8266 and ESP32 boards.

and Ethernet, as well as basic serial UART connectivity. The Bluetooth interface supports both 'classic' and Bluetooth Low Energy (BLE) operation. The IEEE 802.1-compatible Wi-Fi can be configured in access point (AP) mode as well as client and station mode. The former allows the ESP32 to set up its own local wireless network, while the latter provides a way to connect to the Internet using your existing Wi-Fi network.

Low-power operation

The ESP32's minimal power requirements are ideal for applications that need battery power. The ESP32 can be put into 'deep sleep' mode requiring only a few microamps from a battery supply.

Dual-core processor

Most ESP32 modules and boards are based on dual-core architecture and, where necessary, code can be run simultaneously and independently on the two cores.

Firmware

The ESP32 board is supplied with FreeRTOS firmware installed. This powerful, well-documented open-source OS (operating system) supports multi-tasking and provides a vast array of API (application programming interface) functions.

Extensive I/O

The ESP32 supports a wide variety of external hardware. It has inbuilt DAC, ADC, PWM and touch sensing functionality, as well as I^{2}C, SPI and serial UART interface compatibility.

Ease of coding

Coding is straightforward and can be based on the Arduino IDE or other popular software development tools (see later).

Low-coast and wide availability

ESP32-based modules and Devkits are available from several suppliers at very low cost (typically around £5 to £10 for a complete development board).

What is an ESP32?

ESP32 is a generic name that describes Espressif's family of powerful System on Chip (SoC) devices. The name has also been used to describe modules and a plethora of development boards (Devkits) based on this processor. The ESP32 SoC follows on from the success of its predecessor, the ESP8266, but incorporates several important new features (see Fig.1.2).

Supplied as an SoC package, the ESP32 is designed to be embedded in systems designed for specific applications, such as access control, environmental monitoring, machine control and home automation. When supplied in the form of a module, the ESP32 is mounted on a small daughter board that typically includes external circuitry such as a printed Wi-Fi antenna.

Taking it one step further, development boards, known as 'Devkits', offer an enhanced experience for experimentation and learning. They provide a generous subset of the ESP32's I/O pins, along with a USB programming interface and a voltage regulator. Our *Teach-In* series focuses on the most popular Devkits using the ESP-WROOM-32 module. These boards are available in both 30- and 36-pin versions. Although either version can be used to follow our series, we have used the smaller 30-pin board in most of our practical layout diagrams. The ESP-WROOM-32 has the impressive specification listed in Table 1.1.

Finally, if you happen to already have experience of the Arduino UNO, you will find that the ESP32 has been made available in board configurations matching that of the UNO (see Fig.1.3). This neat arrangement makes it possible to use peripheral hardware designed for the UNO with an ESP32 SoC. The ESP32 has even been integrated into the latest Arduino UNO R4 Wi-Fi. This merges the RA4M1 processor from Renesas with the ESP32-S3 from Espressif, a really powerful and versatile combination.

Table 1.1 ESP-WROOM-32 specification

Feature	Specification	Notes
Processor	32-bit dual core, 40nm process	Single-core versions are also available
Processor speed	160 or 240 MHz	
ROM	448kB	Booting and core function storage
SRAM	520kB	Instructions and data storage
External memory	Up to 32Mb of flash memory	
DAC	2 × 8-bit	
ADC	18 channels × 12-bit	SAR type ADC
GPIO	34 programmable pins	See Table 1.2 for limitations
SPI	Four channels	
I^{2}S	Two channels	2-wire connection
I^{2}C	Two channels	3-wire connection
UART	Three serial ports	
Wi-Fi	IEEE 802.11 b/g/n	
Bluetooth	V4.2 BR/EDR and BLE 1	
Ethernet	MAC interface with dedicated DMA	
RTC		Time is retained in various sleep modes
Memory controller	SD/SDIO/CE-ATA/MMC/ MMC host controller	For external memory
LED and motor PWM	Up to 16 channels	
IR remote controller	TX/RX up to 8 channels	
Touch sensors	10 capacitive touch sensor inputs	Via GPIO pins
Power	+3.3V or +5V from a USB connector	Deep sleep supply current can be as low as a few µA

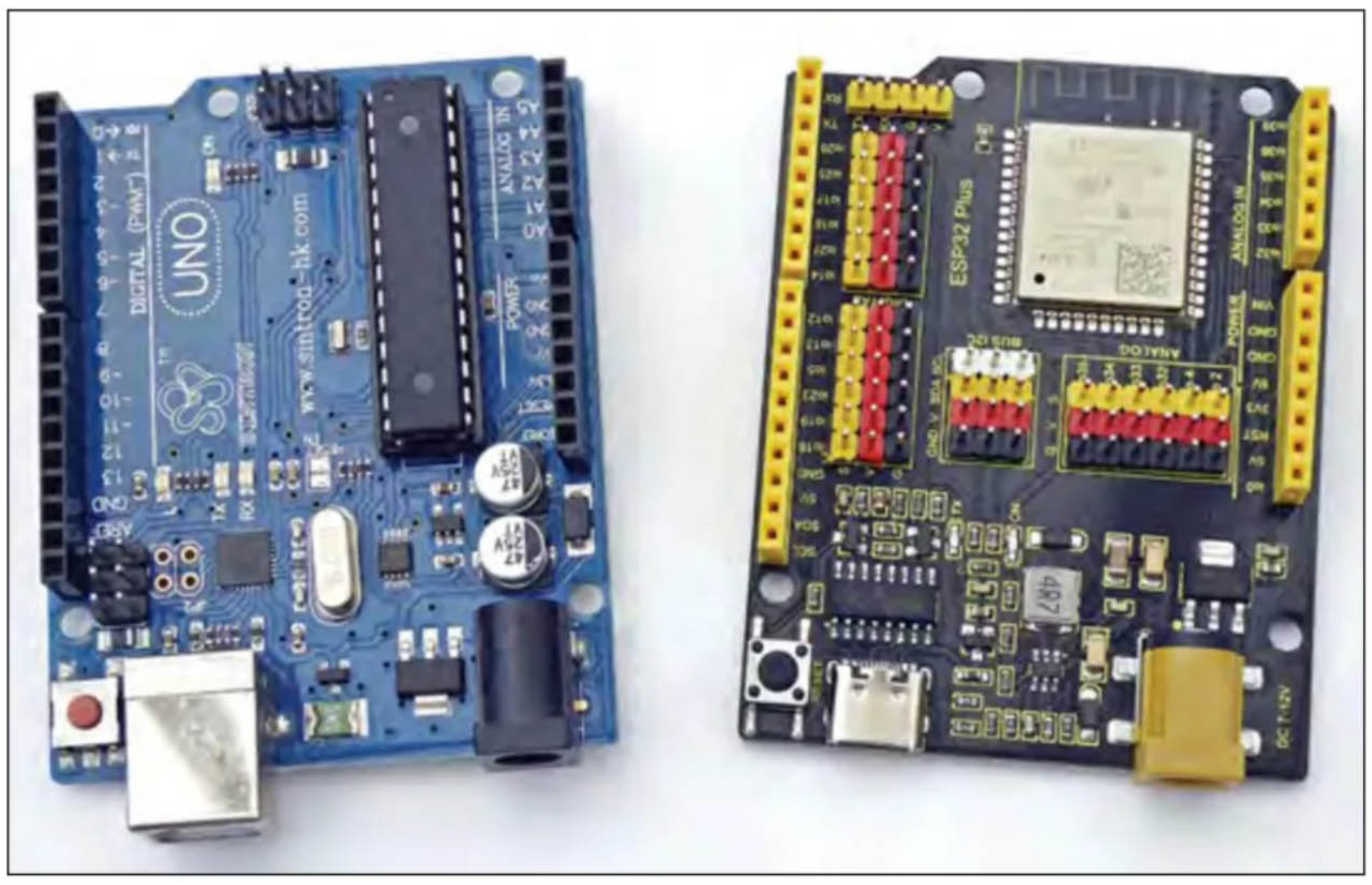


Fig.1.3. (left) An Arduino UNO and an ESP32 development board sharing the same form factor.

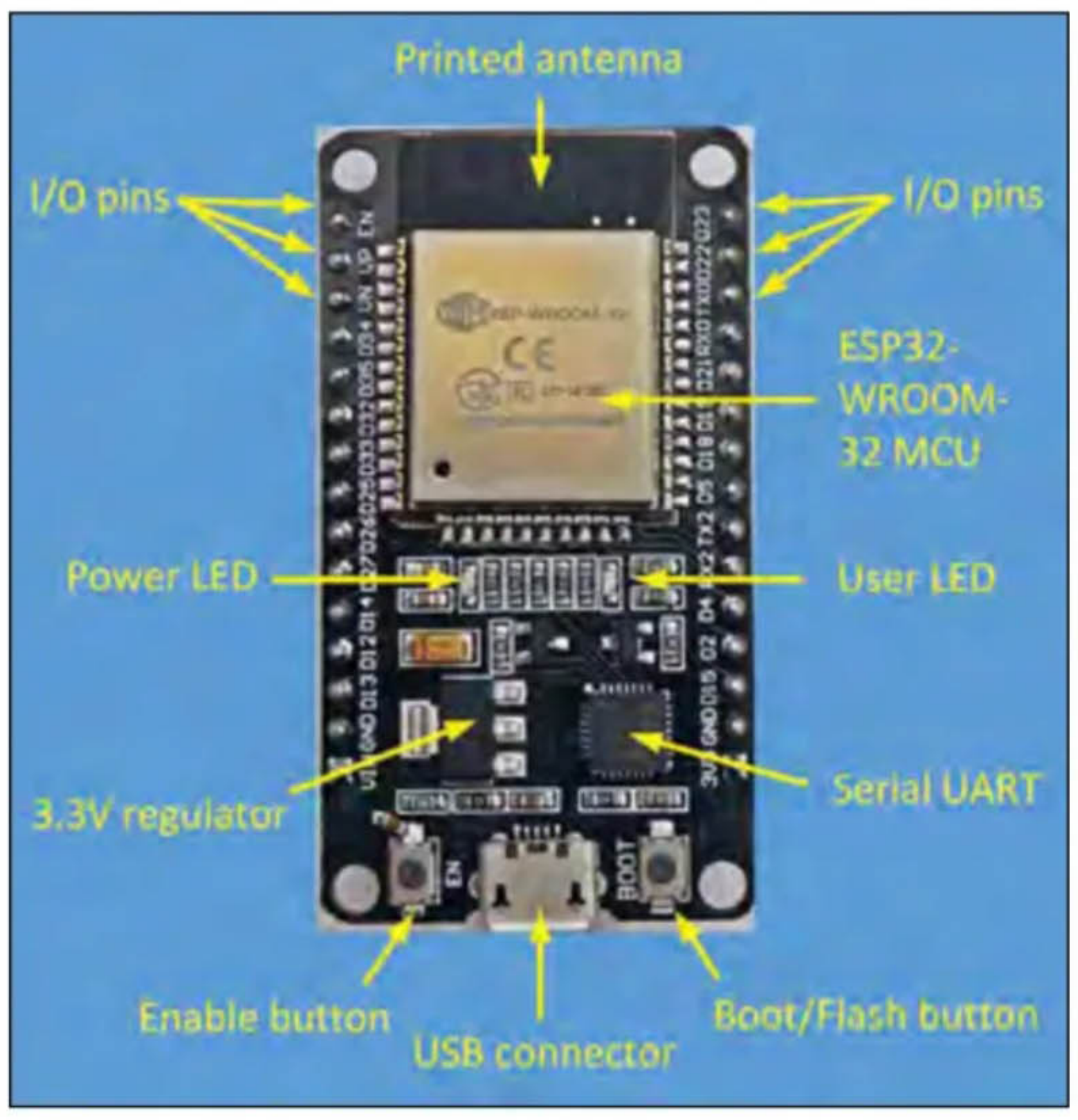

Printed antenna
I/O pins
I/O pins
ESP32-WROOM-32 MCU
Power LED
User LED
3.3V regulator
Serial UART
Enable button
USB connector
Boot/Flash button

Fig.1.4. (right) Typical ESP32 development board layout.

What we will be covering

Regular features of this new *Teach-In* series will include the following sections and features:

Check it out!

Put simply, this will be the point at which you can stop reading and start your practical investigation of the concepts that we've introduced in the text. *Check it out!* will reinforce your learning by putting ideas and techniques into context.

Practical project

Our practical project will showcase the topics covered each month. Most practical projects can be completed in a couple of hours and parts can be saved for use in later projects.

Coding workshop

We will develop coding skills progressively throughout the series and, while this isn't a series about coding, it's important to be able to understand what the code does and how your coding style can be improved.

Teach-In challenge

After completing our practical project you might be keen to try something yourself. Our monthly *Teach-In challenge* will set you a task and give you something to get your teeth into. We will provide a few pointers along the way, but the solution will always be in *your* hands.

Finally, and to help you avoid some potential pitfalls along the way, we've included some short *Gotcha!* hints and tips, providing pointers and solutions to problems that you might encounter in your projects. We've added these at the points at which you are most likely to need them. You will find five of them in this first part – hopefully they will help you avoid the painful head scratching that we experienced when putting the series together!

What you will need

Just like previous *Teach-In* series, you will need a few basic items to explore the showcased examples and to construct the projects featured each month. We've strived to ensure that the requirements are simple, inexpensive and we suspect that most of our readers will already have many of the items to hand. If that's not the case, you will find numerous suppliers online, mentioned in the pages of *PE*, and listed in our *Going further* feature each month. To get started this month you will need:

- Low-cost ESP32 microcontroller development/Devkit board (see later)
- Low-cost breadboard with jumper leads for connecting to external circuitry
- USB cable to connect the development board to your PC
- Copy of the freely available Arduino integrated development environment (IDE) installed on your PC (see later)
- 5V USB charging power pack for remote and stand-alone operation of some of your projects
- Standard red LED and a 150Ω resistor.

Coding and the ESP32

The ESP32 can be used with several popular programming environments, including:

- Arduino IDE
- PlatformIO IDE (VS Code)
- LUA
- MicroPython
- Espressif IDF (IoT Development Framework).

Since many readers will already be familiar with the Arduino IDE, this is

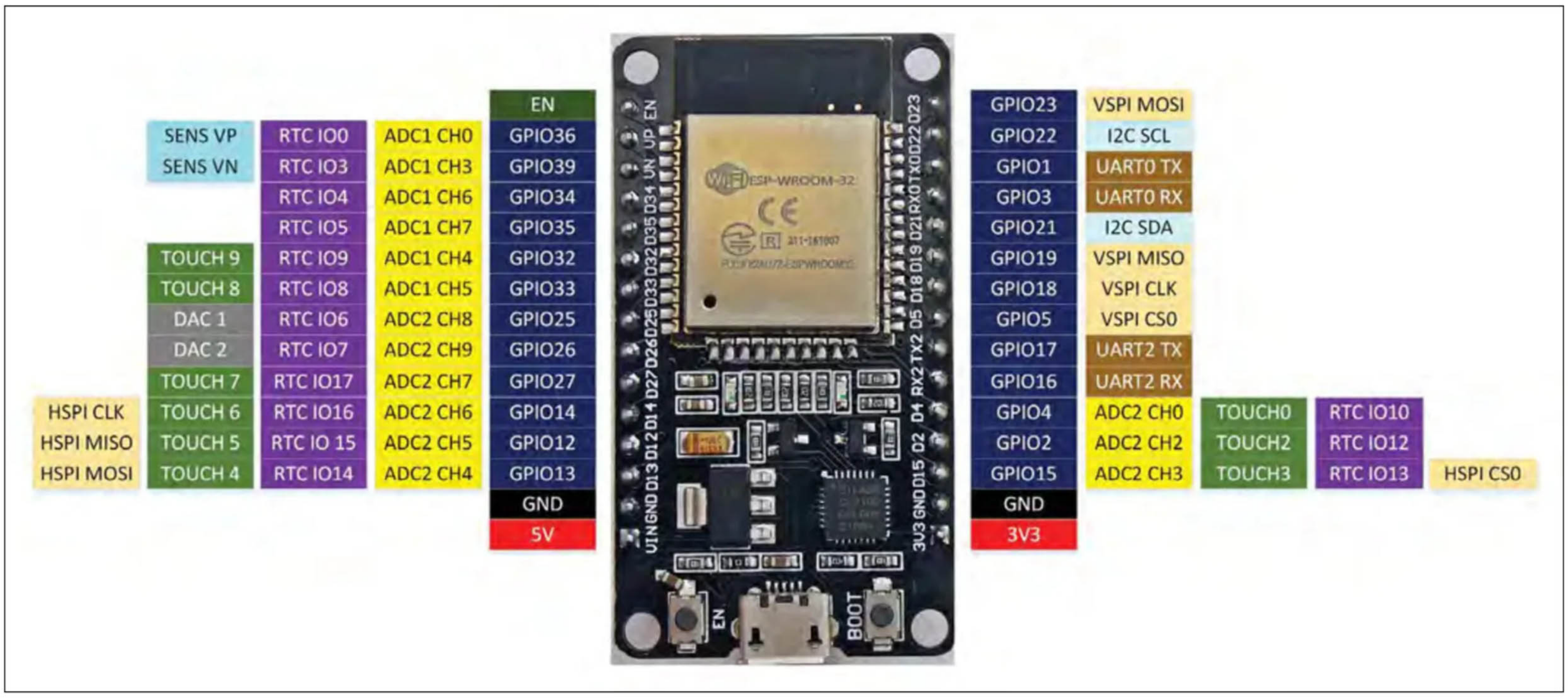

EN
SENS VP RTC IO0 ADC1 CH0 GPIO36
SENS VN RTC IO3 ADC1 CH3 GPIO39
RTC IO4 ADC1 CH6 GPIO34
RTC IO5 ADC1 CH7 GPIO35
TOUCH 9 RTC IO9 ADC1 CH4 GPIO32
TOUCH 8 RTC IO8 ADC1 CH5 GPIO33
DAC 1 RTC IO6 ADC2 CH8 GPIO25
DAC 2 RTC IO7 ADC2 CH9 GPIO26
TOUCH 7 RTC IO17 ADC2 CH7 GPIO27
HSPI CLK TOUCH 6 RTC IO16 ADC2 CH6 GPIO14
HSPI MISO TOUCH 5 RTC IO 15 ADC2 CH5 GPIO12
HSPI MOSI TOUCH 4 RTC IO14 ADC2 CH4 GPIO13
GND
5V
GPIO23 VSPI MOSI
GPIO22 I2C SCL
GPIO1 UART0 TX
GPIO3 UART0 RX
GPIO21 I2C SDA
GPIO19 VSPI MISO
GPIO18 VSPI CLK
GPIO5 VSPI CS0
GPIO17 UART2 TX
GPIO16 UART2 RX
GPIO4 ADC2 CH0 TOUCH0 RTC IO10
GPIO2 ADC2 CH2 TOUCH2 RTC IO12
GPIO15 ADC2 CH3 TOUCH3 RTC IO13 HSPI CS0
GND
3V3
EN
BOOT

Fig.1.5. Pin connections for a typical 30-pin ESP32 development board.

Table 1.2 Recommended GPIO pins for general use

Designation	Function	Direction	Comment
GPIO0	TX0 (serial port)	O	Serial programming and debugging
GPIO2	User LED	I/O	Avoid external connection
GPIO3	RX0 (serial port)	I	Serial programming and debugging
GPIO4	I/O	I/O	Available for general use
GPIO5	I/O	I/O	Strapping pin – avoid
GPIO6-11	Flash memory	n/a	Avoid external connection
GPIO12	I/O	I/O	Strapping pin – avoid
GPIO13-14	I/O	I/O	Available for general use
GPIO15	I/O	I/O	Mutes debugging messages
GPIO16-33	I/O	I/O	Available for general use
GPIO34-39	I/O	I	Input only

Example code

```
/* On-board LED flasher */
int ledPort = 2;  // GPIO2 is connected to the LED

// Initialise the port
void setup() {
  pinMode(ledPort, OUTPUT);
}

// Loop forever
void loop() {
  digitalWrite(ledPort, HIGH);  // Set LED on
  delay(1000);                  // 1s delay
  digitalWrite(ledPort, LOW);   // Set LED off
  delay(1000);                  // 1s delay
}
```

the platform that we will be using. The IDE is reasonably intuitive and is free to download and use. It is also exceptionally well supported with reference tutorial material and extensible with code libraries for a huge variety of peripheral devices. To give you some idea of just how easy ESP32 programming can be, above is some example code that will flash the ESP32's on-board LED on and off at 1s intervals. You should be able to get an idea of what the code does even if you've never seen it before!

Notice that this code includes some comments (inserted *between* the '/*' and '*/' characters and also after the '//' characters). Even though they have no impact on the execution of your code, these comments are invaluable – top tip, do keep them short and meaningful.

Coding is an iterative process based on a repeated cycle of entering (or editing) code, uploading to the target system, executing, debugging and optimising your code. You may find that you have to loop through this cycle many times before your code executes in the way that you need. You will also find that once you've developed a block of code that works well you will be able to reuse it in other situations. This is another reason why it is important to comment your code so that you can understand what it does, how to use it, and – where necessary – adapt it.

What's on the board?

Fig.1.4 shows a typical development board. We've labelled the board to show you the most important features. You will notice that the external pin connections run along the two longer sides of the board, while the printed Wi-Fi antenna and USB connector are located at the opposite ends. Adjacent to the USB connector are two small buttons, labelled EN (enable) and BOOT. These buttons are used to restart the system and for uploading code respectively. There are two LEDs on the board. The Power LED indicates that power is present, while the User LED is available for test purposes. We will make use of this later.

Gotcha!

There are many ESP32 development boards available from different suppliers and manufacturers. The features, layout and pinout may vary from those shown in Fig.1.4. We've used the most common subset of pins and connections in this series, but it is important to check the layout and configuration of your board before making *any* connections to it, or applying power.

The ESP32's GPIO pin configuration is summarised in Table 1.2. Note that GPIO pins have multiple functions, and some are unsuitable for general use. Those shown shaded in green are recommended for general purpose use.

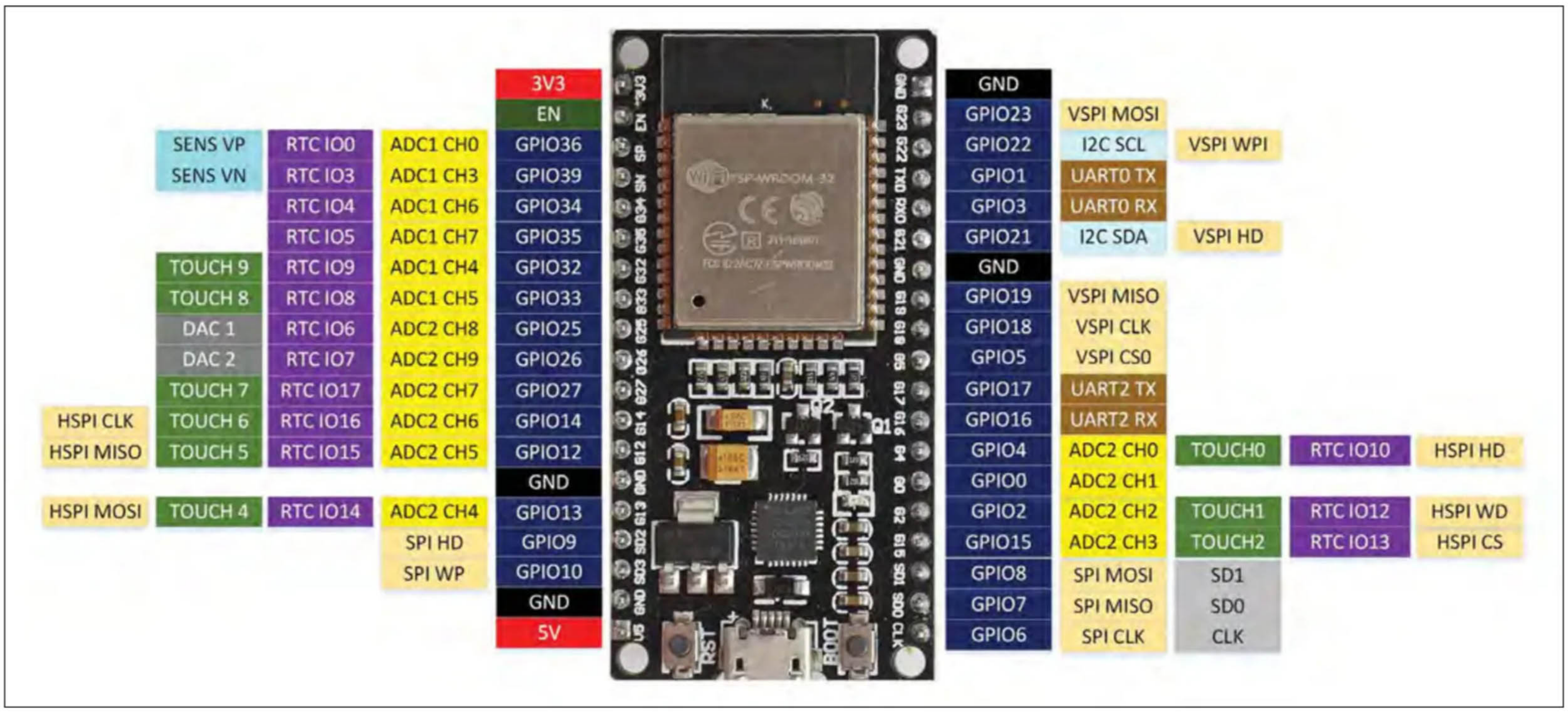

3V3
EN
SENS VP RTC IO0 ADC1 CH0 GPIO36
SENS VN RTC IO3 ADC1 CH3 GPIO39
RTC IO4 ADC1 CH6 GPIO34
RTC IO5 ADC1 CH7 GPIO35
TOUCH 9 RTC IO9 ADC1 CH4 GPIO32
TOUCH 8 RTC IO8 ADC1 CH5 GPIO33
DAC 1 RTC IO6 ADC2 CH8 GPIO25
DAC 2 RTC IO7 ADC2 CH9 GPIO26
TOUCH 7 RTC IO17 ADC2 CH7 GPIO27
HSPI CLK TOUCH 6 RTC IO16 ADC2 CH6 GPIO14
HSPI MISO TOUCH 5 RTC IO15 ADC2 CH5 GPIO12
GND
HSPI MOSI TOUCH 4 RTC IO14 ADC2 CH4 GPIO13
SPI HD GPIO9
SPI WP GPIO10
GND
5V
GND
GPIO23 VSPI MOSI
GPIO22 I2C SCL VSPI WPI
GPIO1 UART0 TX
GPIO3 UART0 RX
GPIO21 I2C SDA VSPI HD
GND
GPIO19 VSPI MISO
GPIO18 VSPI CLK
GPIO5 VSPI CS0
GPIO17 UART2 TX
GPIO16 UART2 RX
GPIO4 ADC2 CH0 TOUCH0 RTC IO10 HSPI HD
GPIO0 ADC2 CH1
GPIO2 ADC2 CH2 TOUCH1 RTC IO12 HSPI WD
GPIO15 ADC2 CH3 TOUCH2 RTC IO13 HSPI CS
GPIO8 SPI MOSI SD1
GPIO7 SPI MISO SD0
GPIO6 SPI CLK CLK
ESP-WROOM-32
EN
BOOT
RST

Fig.1.6. Pin connections for a typical 36-pin ESP32 development board.

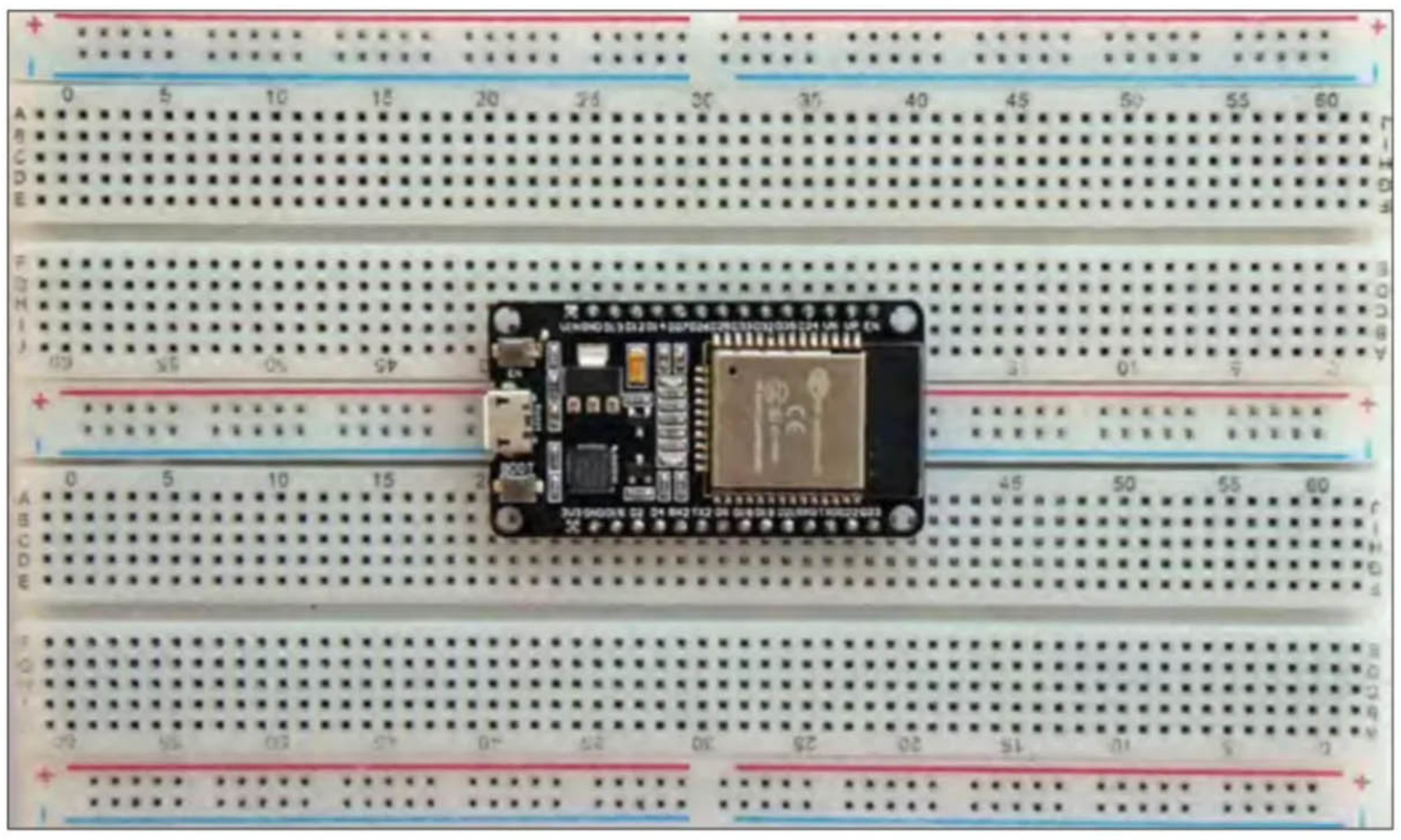


Fig.1.7. Two (slightly modified) breadboards provide a convenient space for a 30-pin ESP32 development board.

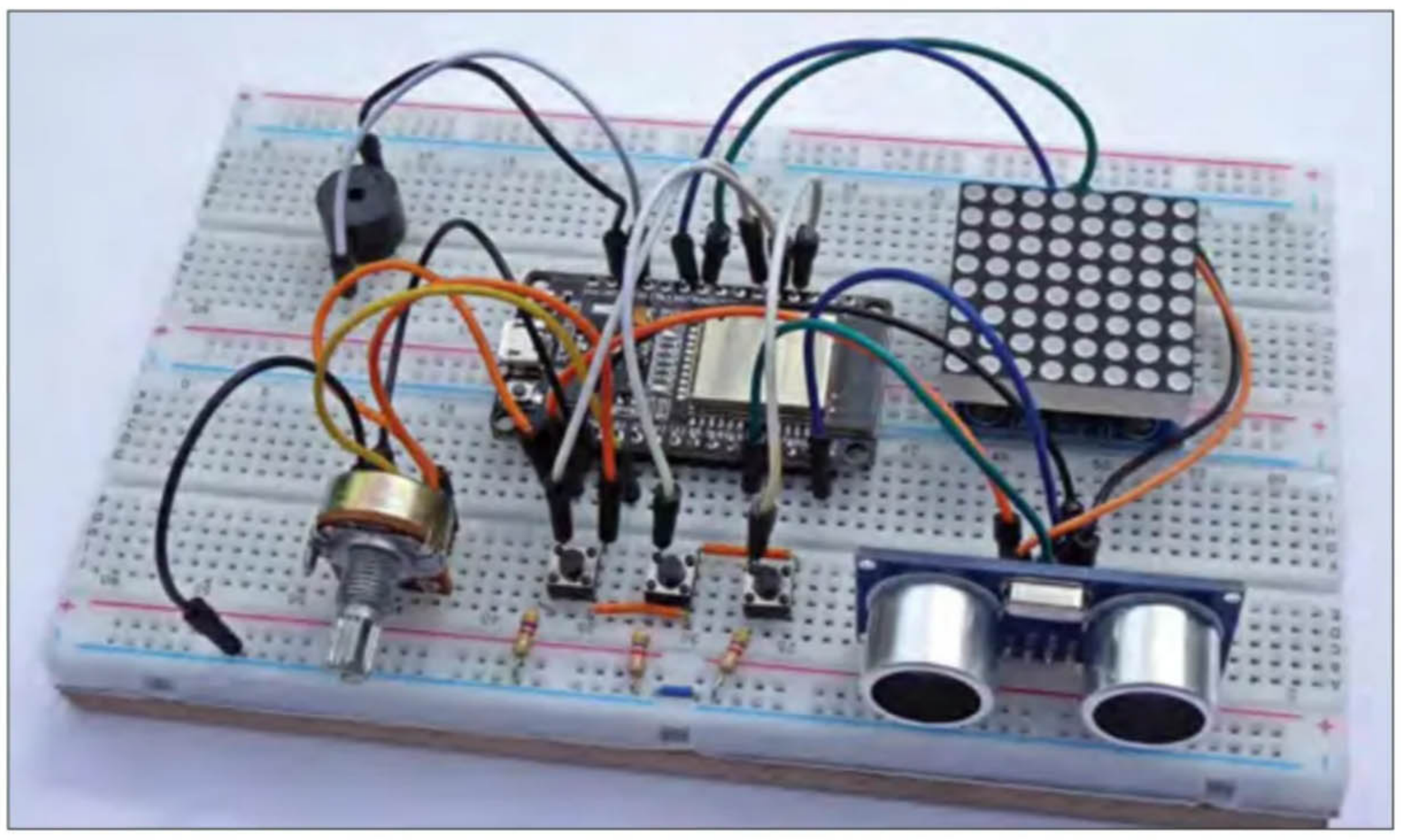


Fig.1.8. A typical breadboard circuit arrangement ready for testing.

Gotcha!

Several different pin configurations are found on ESP32 development boards. The most common of which use either 30 or 36-pins. There may also be minor differences in the way in which the pins are marked on the boards. You may also find that not all the GPIO pins listed in Table 1.2 are available on your board. The ones that are 'safe' for general purpose use are shaded in green.

Pin connections for typical 30- and 36-pin ESP32 development boards are shown in Figs.1.5 and 1.6 respectively. We have shown the different signal functions for the GPIO pins on this diagram. Notice how the GPIO pin numbering is not always consecutive and how some pins can have up to five different functions. For example, GPIO4 can be configured for use:

- As a normal digital I/O pin
- As an analogue input (Channel 0 of ADC2)
- As a touch sensing input
- In conjunction with the real-time clock (RTC)
- As a means of connecting an SPI (serial peripheral interface) device.

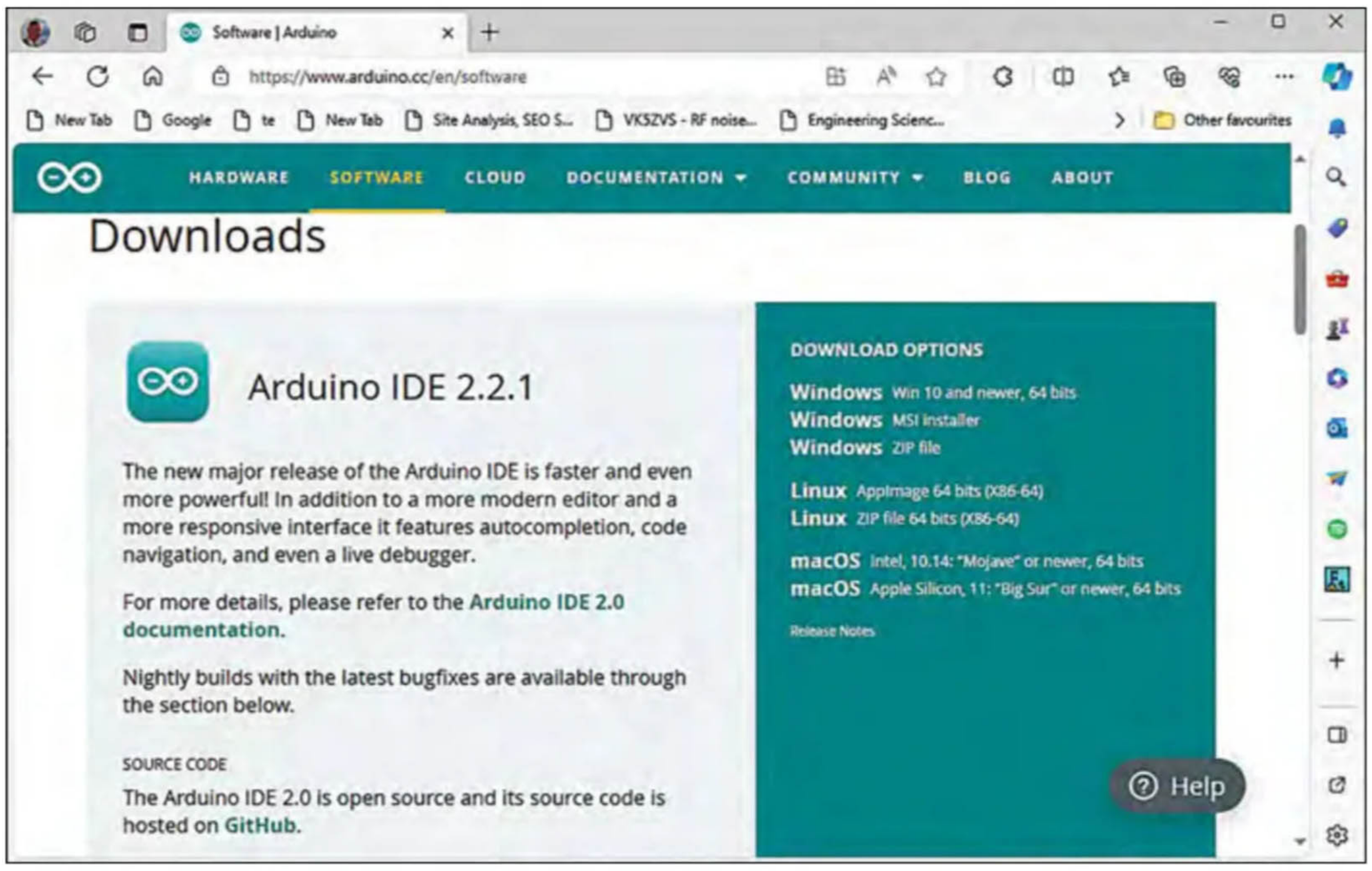
This may sound baffling at first, but it will become clearer when we look at some practical examples of how the chip is used and interfaced to external devices.

Breadboards

You will need a breadboard to connect electronic components to your development board. These are available in various sizes and with different numbers of connecting points. For *Teach-In*, and because of the size of the ESP32 development board we've standardised on an arrangement based on two separate breadboards placed side-by-side. We've also modified one of the boards by unclipping and removing one of the supply rails (red and blue) before glueing the two boards onto a small piece of MDF. Fig.1.7 shows how this is done, and Fig.1.8 shows a typical breadboard circuit arrangement with ESP32 and external components connected.

Gotcha!

Whatever breadboard you use it's important to have plenty of space available for mounting components. A cramped layout can quickly become confusing.



Downloads

Arduino IDE 2.2.1

The new major release of the Arduino IDE is faster and even more powerful! In addition to a more modern editor and a more responsive interface it features autocompletion, code navigation, and even a live debugger.

For more details, please refer to the Arduino IDE 2.0 documentation.

Nightly builds with the latest bugfixes are available through the section below.

SOURCE CODE

The Arduino IDE 2.0 is open source and its source code is hosted on GitHub.

DOWNLOAD OPTIONS

Windows Win 10 and newer, 64 bits
Windows MSI installer
Windows ZIP file

Linux AppImage 64 bits (X86-64)
Linux ZIP file 64 bits (X86-64)

macOS Intel, 10.14: "Mojave" or newer, 64 bits
macOS Apple Silicon, 11: "Big Sur" or newer, 64 bits

Release Notes

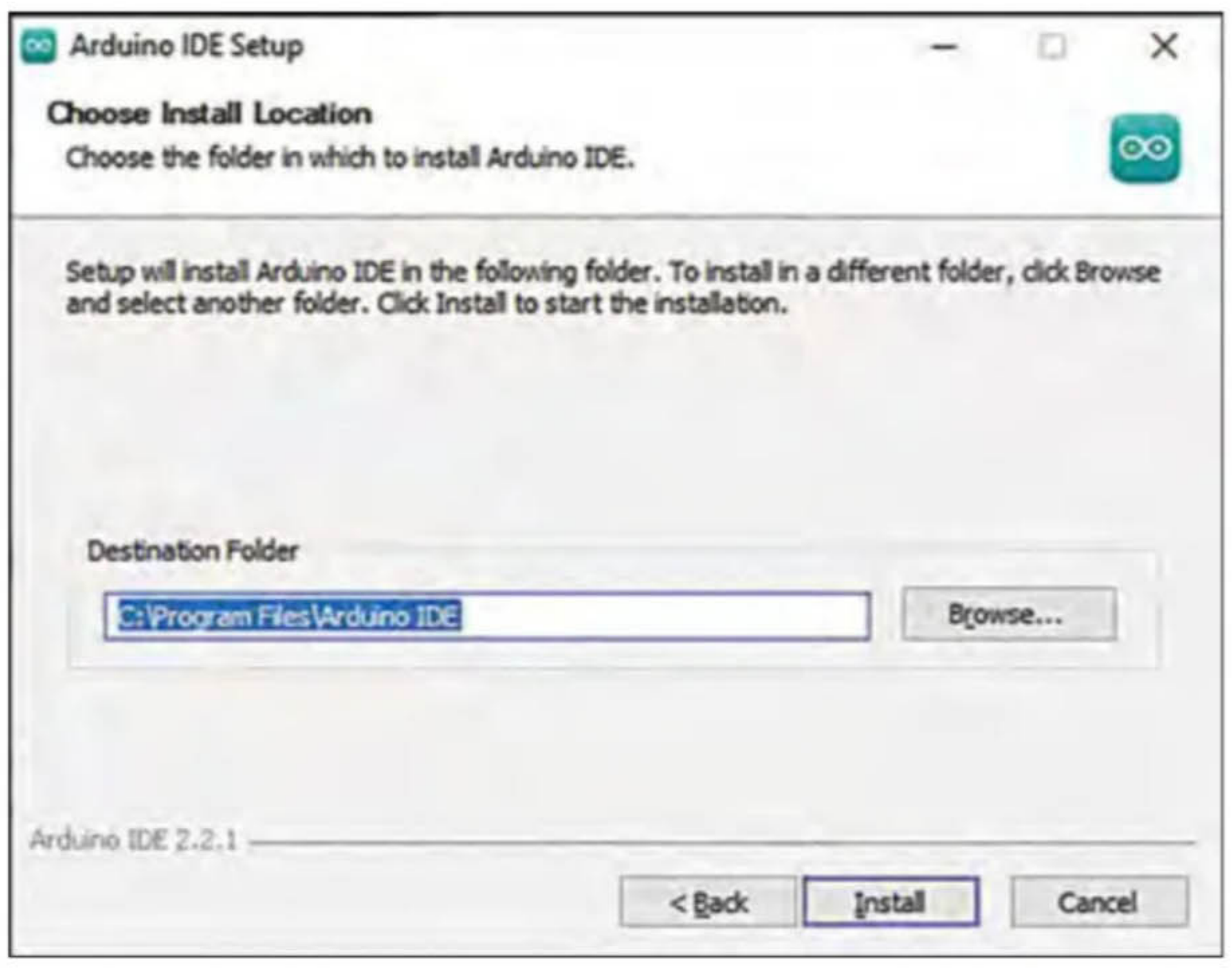
Fig.1.9. Selecting the IDE installer for your computer.

Installing and configuring the Arduino IDE

Before you can begin to enter code into your ESP32 you will need to connect it to a PC that has a copy of the Arduino's integrated development environment (IDE) installed on it. The process is quite painless, but it requires an Internet connection so that you can download the latest version of the IDE package.

We've installed the IDE package successfully on a whole host of different computers, including some running 32- and 64-bit versions of Windows and also a couple running different flavours of Linux. The step-by-step procedure described here was carried out on a computer running Windows 10, but the process is similar, if not quite identical, on other machines. Note that an installation under Linux may require the installation of the Java run-time environment (JRE) if not already installed.

1. Open your Web browser and go to **www.arduino.cc** (the official Arduino home page). When the page has loaded click on 'Software' to open the downloads page. Then scroll down to the latest version of the Arduino IDE (currently 2.2.1) which usually appears at the top of the list. Next, select the installer for your machine (we chose the Windows 10 64-bit installer) from the list on the right.



Choose Install Location

Choose the folder in which to install Arduino IDE.

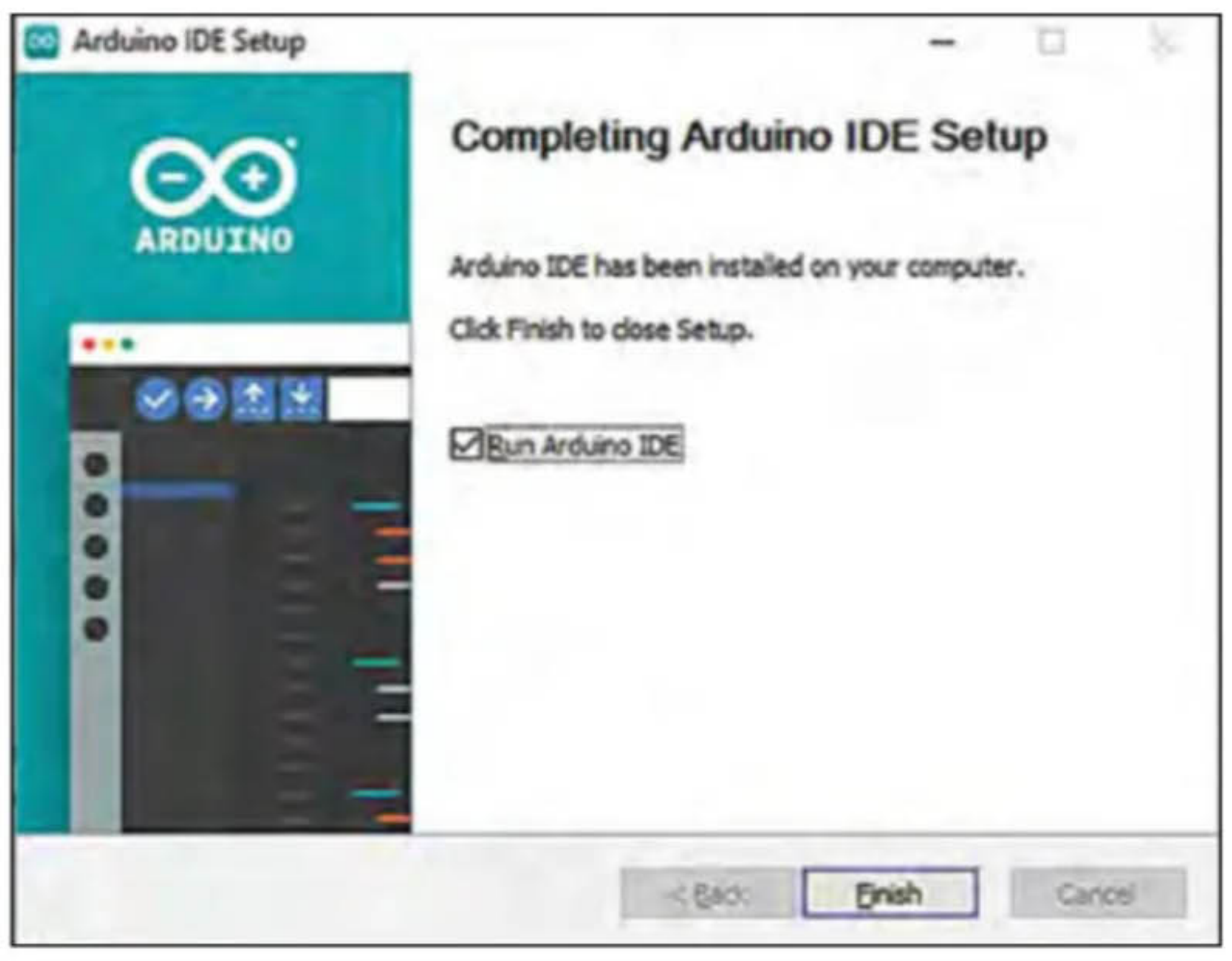
Setup will install Arduino IDE in the following folder. To install in a different folder, click Browse and select another folder. Click Install to start the installation.

Destination Folder

C:\Program Files\Arduino IDE

Arduino IDE 2.2.1

Fig.1.10. Selecting the destination folder for your installation.



Completing Arduino IDE Setup

Arduino IDE has been installed on your computer.

Click Finish to close Setup.

☑ Run Arduino IDE

Fig.1.11. The Arduino IDE has been successfully installed and is ready to run.

2 At this point you will be asked if you would like to make a contribution (see Fig.1.10). You can either click on 'Just download' or 'Contribute and download'. When you've made your choice the installation file will be downloaded to your computer. The download is quite large, so, depending on the speed of your Internet connection, you may have to wait for a minute or two for the download to complete.

3 Next, click on the installer or unzip the file (depending on which version you have chosen) and simply follow the prompts. You can choose a destination folder (see Fig.1.10) or just accept the default. Finally, click on 'Install' to start the installation process.

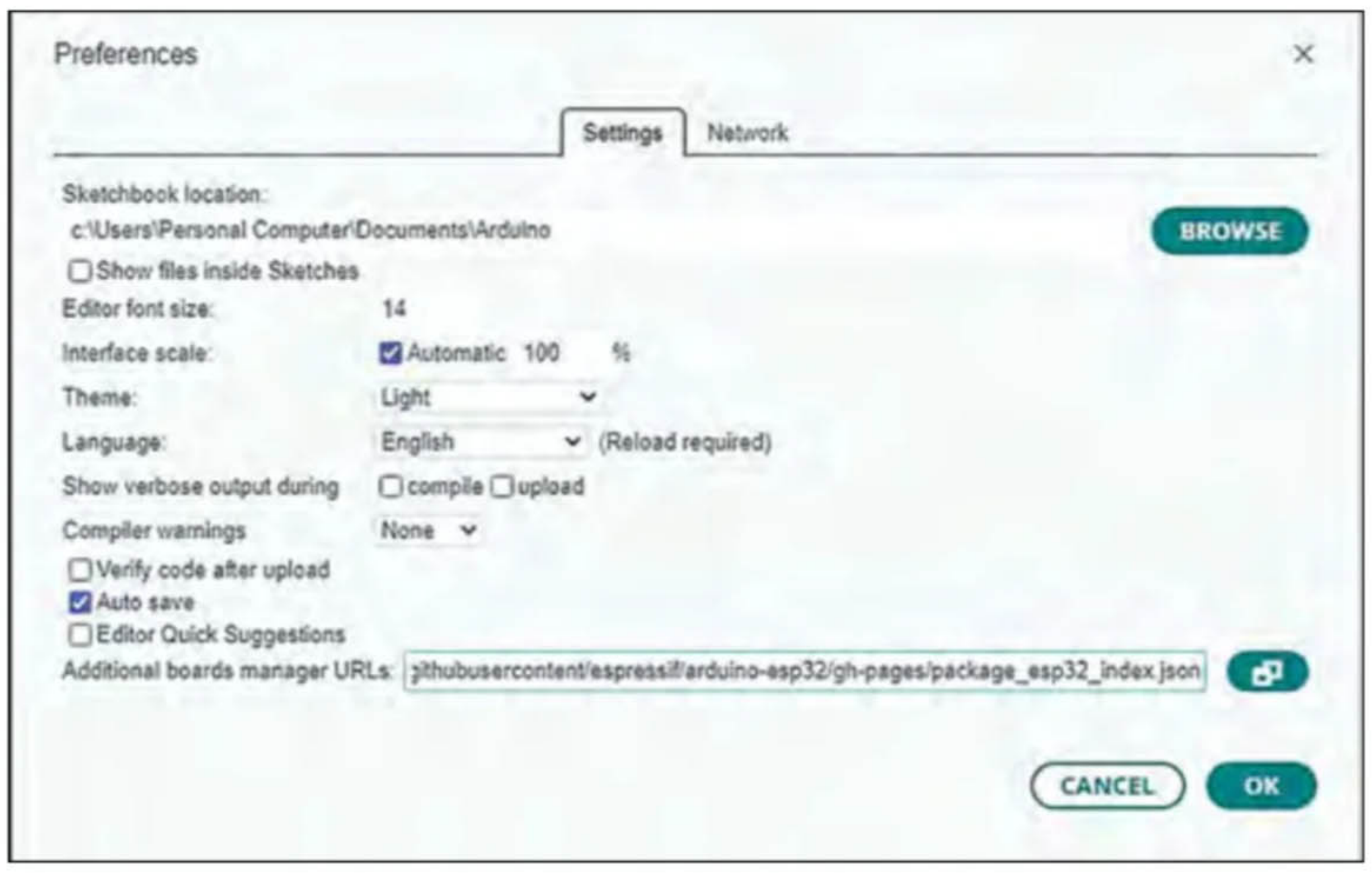
4 Depending on the speed of your computer the installation process may take as little as 30 seconds or up to several few minutes. You may also be given the option of installing a USB driver. This driver will allow your computer to communicate with a standard Arduino by means of the USB port. We recommend that you click on 'Install' to install this additional system software (this is not part of the IDE itself).

5 When the installation is complete (and when any USB driver has been added) you can click on 'Finish' and either return to your normal desktop or, if you've checked the 'Run Arduino IDE' (see Fig.1.11) you can run the IDE and get started right away.

6 To install the extra libraries and code for the ESP32 you will need to tell the IDE where to go to fetch the required files. Run the IDE (if not already running), select 'File' from the menu bar and then 'Preferences'. Next, you will need to manually enter the URL in the dialogue box (see Fig.1.12). The URL is rather long but here it is:

https://raw.githubusercontent.com/espressif/arduino-esp32/gh-pages/package_esp32_index.json

Just enter the above URL (exactly as shown in Fig.1.12) and then click on 'OK'.



Sketchbook location:
c:\Users\Personal Computer\Documents\Arduino
☐ Show files inside Sketches
Editor font size: 14
Interface scale: ☑ Automatic 100 %
Theme: Light
Language: English (Reload required)
Show verbose output during ☐ compile ☐ upload
Compiler warnings None
☐ Verify code after upload
☑ Auto save
☐ Editor Quick Suggestions
Additional boards manager URLs: githubusercontent/espressif/arduino-esp32/gh-pages/package_esp32_index.json

Fig.1.12. A URL is used to locate the code needed to configure the IDE for the ESP32.

7 Next, select 'Tools', 'Board' and 'Board Manager' from the drop-down menu. Scroll down the list of supported boards to the entry headed 'esp32 by Espressif' and then click on 'INSTALL' as shown in Fig.1.13. It may take several minutes for the library files to be downloaded, but during that time the progress bar should be active, and a list of downloaded files should be displayed. After these additional tools have been automatically configured the IDE will be ready for use with the ESP32.

8 Now connect your ESP32 development board to your PC using one of its (powered) USB ports. Note that the USB port supplies +5V power so there's no need for a separate DC supply for the ESP32. With the IDE still open, click on 'Select Board' and 'Select other board and port' (Fig.1.14). Scroll down the list of ESP32 boards (there are quite a few!) until your ESP32 board is listed (usually this will be 'ESP32 Dev Module'). Click to select the board and a tick will appear against it (see Fig.1.15). You should also see that a serial COM port has been identified and allocated to your ESP32. Click on 'OK' to complete the set-up process and your ESP32 is ready for some code!

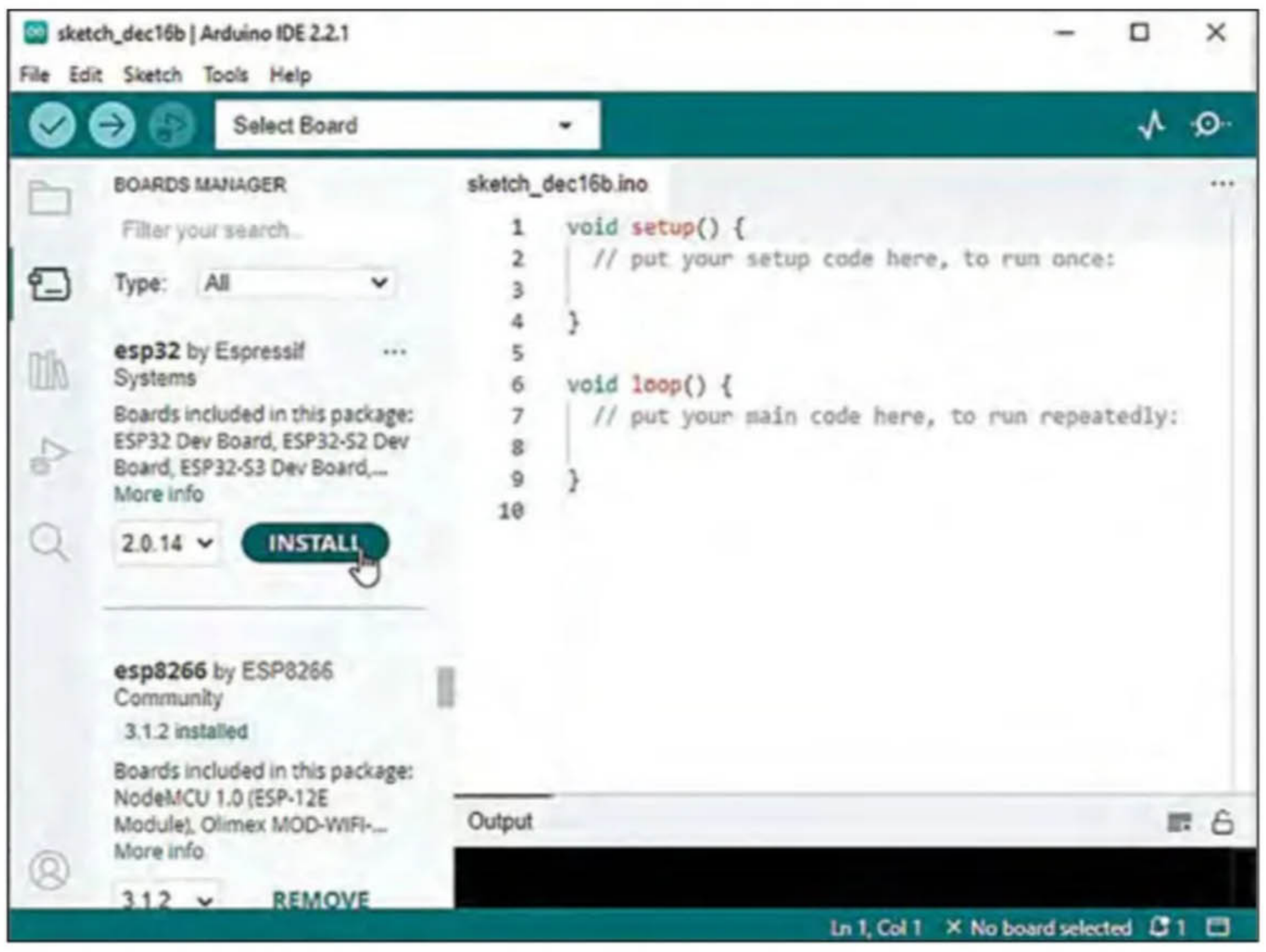
9 You should now be rewarded with a window like the one shown in Fig.1.16. The message in the 'Output' field (at the bottom of the screen) confirms that the ESP32 platform has been installed successfully. Note also that the status bar (also at the bottom of the screen) is reporting that the IDE is connected to an 'ESP32 Dev Module on COM4'. If that's not the case, click on 'Tools', scroll down to 'Board' and 'Port', and hover your mouse over them. If the settings are not correct you will be able to change them.

10 If you are ready to try some code, here's a simple ESP32 application that flashes the built-in LED. Just type the code in Listing 1.1, or download it from March 2024 page of the *PE* website: **https://bit.ly/pe-downloads**

Next, click on the large right arrow (below the menu bar) to verify, compile and upload the code to the ESP32 in executable form. Note that if there are any errors in the entered code the compilation will fail and you will need to locate and correct the errors before trying again. Note also that you can use the 'File' menu to save your code (and also rename it, if required).

Check it out!

Now for an exercise that will introduce you to the ESP32's touch sensors without needing any additional hardware (other



Type: All

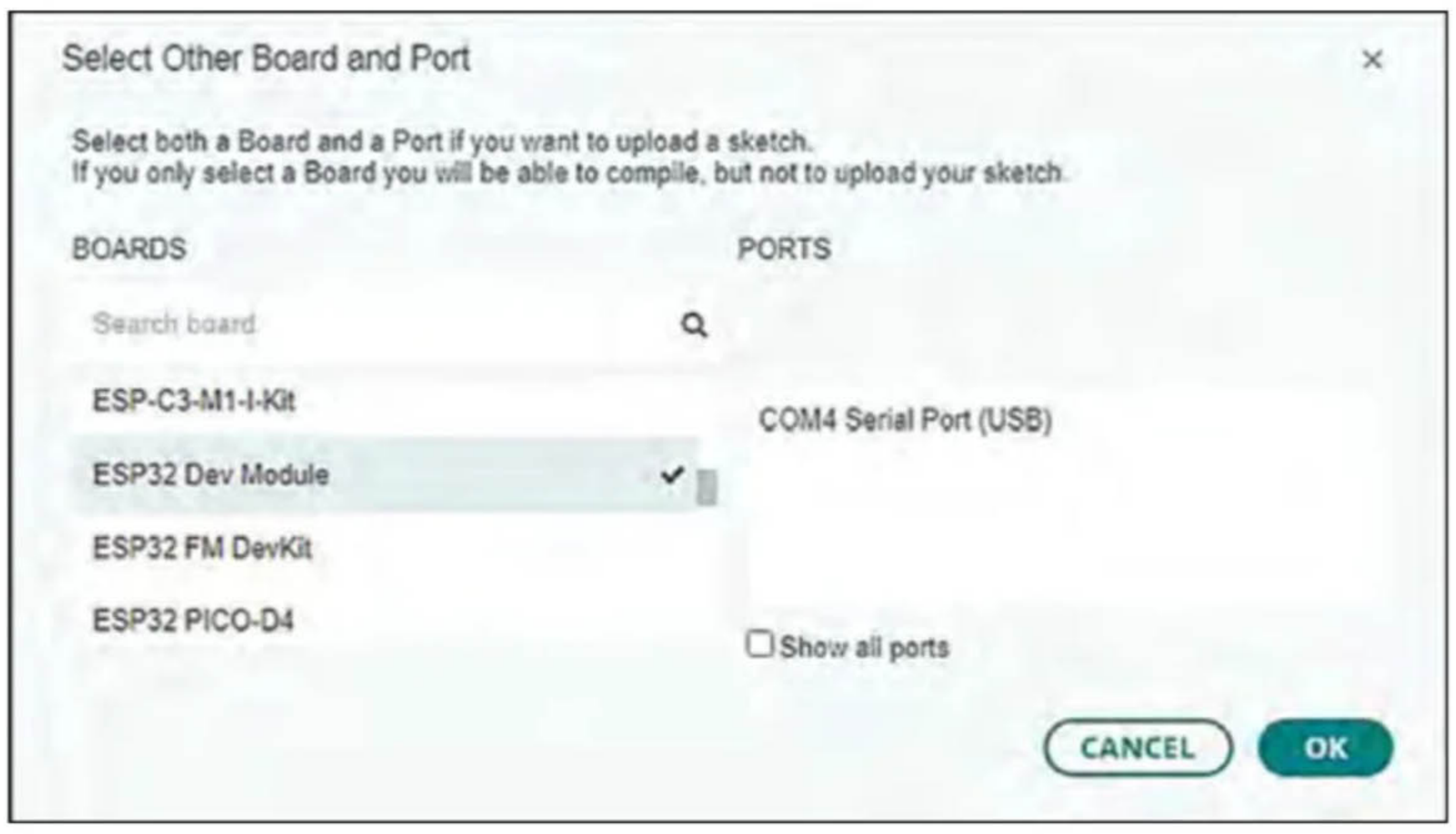
esp32 by Espressif Systems
Boards included in this package: ESP32 Dev Board, ESP32-S2 Dev Board, ESP32-S3 Dev Board,...
More info
2.0.14

esp8266 by ESP8266 Community
3.1.2 installed
Boards included in this package: NodeMCU 1.0 (ESP-12E Module), Olimex MOD-WIFI-...
More info
3.1.2

```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}

```

Ln 1, Col 1 ✕ No board selected 1

Fig.1.13. (left) Using the IDE's Board Manager to install support for the ESP32.



Select both a Board and a Port if you want to upload a sketch.
If you only select a Board you will be able to compile, but not to upload your sketch.

BOARDS
ESP-C3-M1-I-Kit
ESP32 Dev Module ✓
ESP32 FM DevKit
ESP32 PICO-D4

PORTS
COM4 Serial Port (USB)
☐ Show all ports

Fig.1.14. (right) Selecting the ESP board and port.

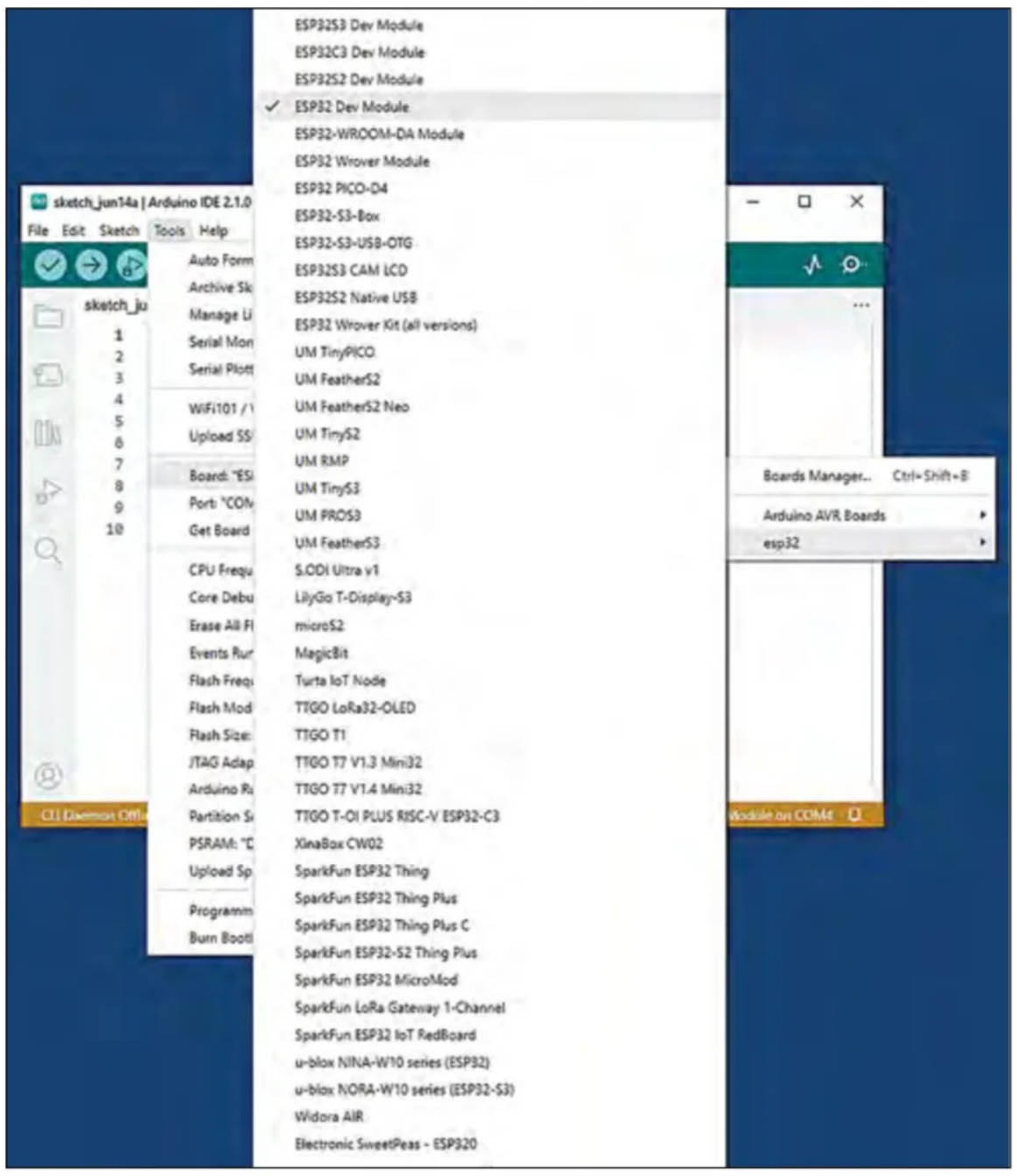
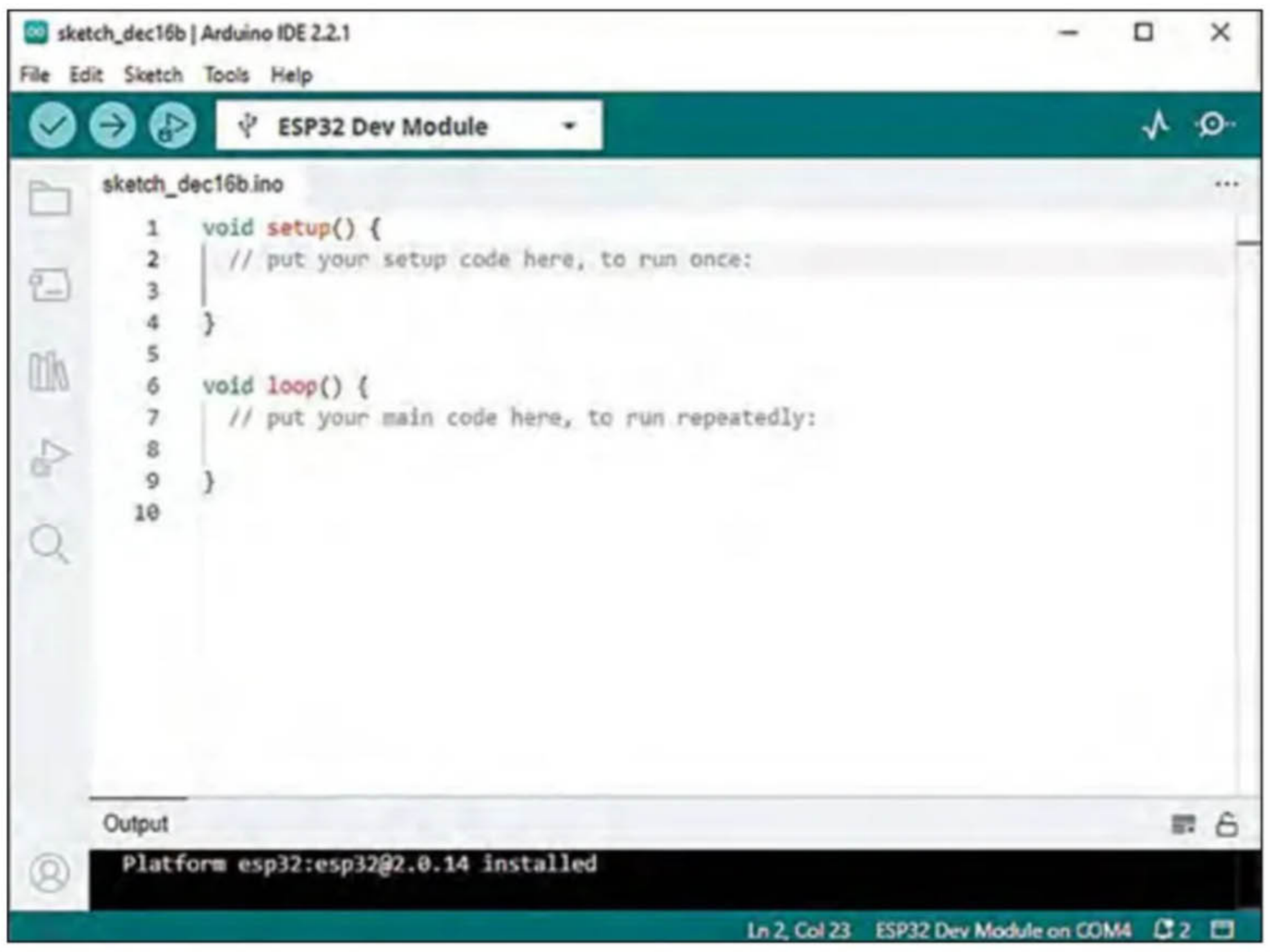

sketch_jun14a | Arduino IDE 2.1.0
File
Edit
Sketch
Tools
Help
Auto Form
Archive Sk
Manage Li
Serial Mon
Serial Plott
WiFi101 / \
Upload SS
Board: "ESI
Port: "CON
Get Board
CPU Frequ
Core Debu
Erase All Fl
Events Rur
Flash Freq
Flash Mod
Flash Size:
JTAG Adap
Arduino R
Partition S
PSRAM: "C
Upload Sp
Programm
Burn Bootl
sketch_ju
ESP32S3 Dev Module
ESP32C3 Dev Module
ESP32S2 Dev Module
✓ ESP32 Dev Module
ESP32-WROOM-DA Module
ESP32 Wrover Module
ESP32 PICO-D4
ESP32-S3-Box
ESP32-S3-USB-OTG
ESP32S3 CAM LCD
ESP32S2 Native USB
ESP32 Wrover Kit (all versions)
UM TinyPICO
UM FeatherS2
UM FeatherS2 Neo
UM TinyS2
UM RMP
UM TinyS3
UM PROS3
UM FeatherS3
S.ODI Ultra v1
LilyGo T-Display-S3
microS2
MagicBit
Turta IoT Node
TTGO LoRa32-OLED
TTGO T1
TTGO T7 V1.3 Mini32
TTGO T7 V1.4 Mini32
TTGO T-OI PLUS RISC-V ESP32-C3
XinaBox CW02
SparkFun ESP32 Thing
SparkFun ESP32 Thing Plus
SparkFun ESP32 Thing Plus C
SparkFun ESP32-S2 Thing Plus
SparkFun ESP32 MicroMod
SparkFun LoRa Gateway 1-Channel
SparkFun ESP32 IoT RedBoard
u-blox NINA-W10 series (ESP32)
u-blox NORA-W10 series (ESP32-S3)
Widora AIR
Electronic SweetPeas - ESP320
Boards Manager... Ctrl+Shift+B
Arduino AVR Boards
esp32
CLI Daemon Offl
Module on COM4

Fig.1.15. Choose your board from the list of supported hardware.


sketch_dec16b | Arduino IDE 2.2.1
File
Edit
Sketch
Tools
Help
ESP32 Dev Module
sketch_dec16b.ino
Output
Ln 2, Col 23
ESP32 Dev Module on COM4

```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

```
Platform esp32:esp32@2.0.14 installed
```

Fig.1.16. The IDE is communicating with the ESP32 Dev Module on COM4 and ready for some code (the code displayed is just a blank template).

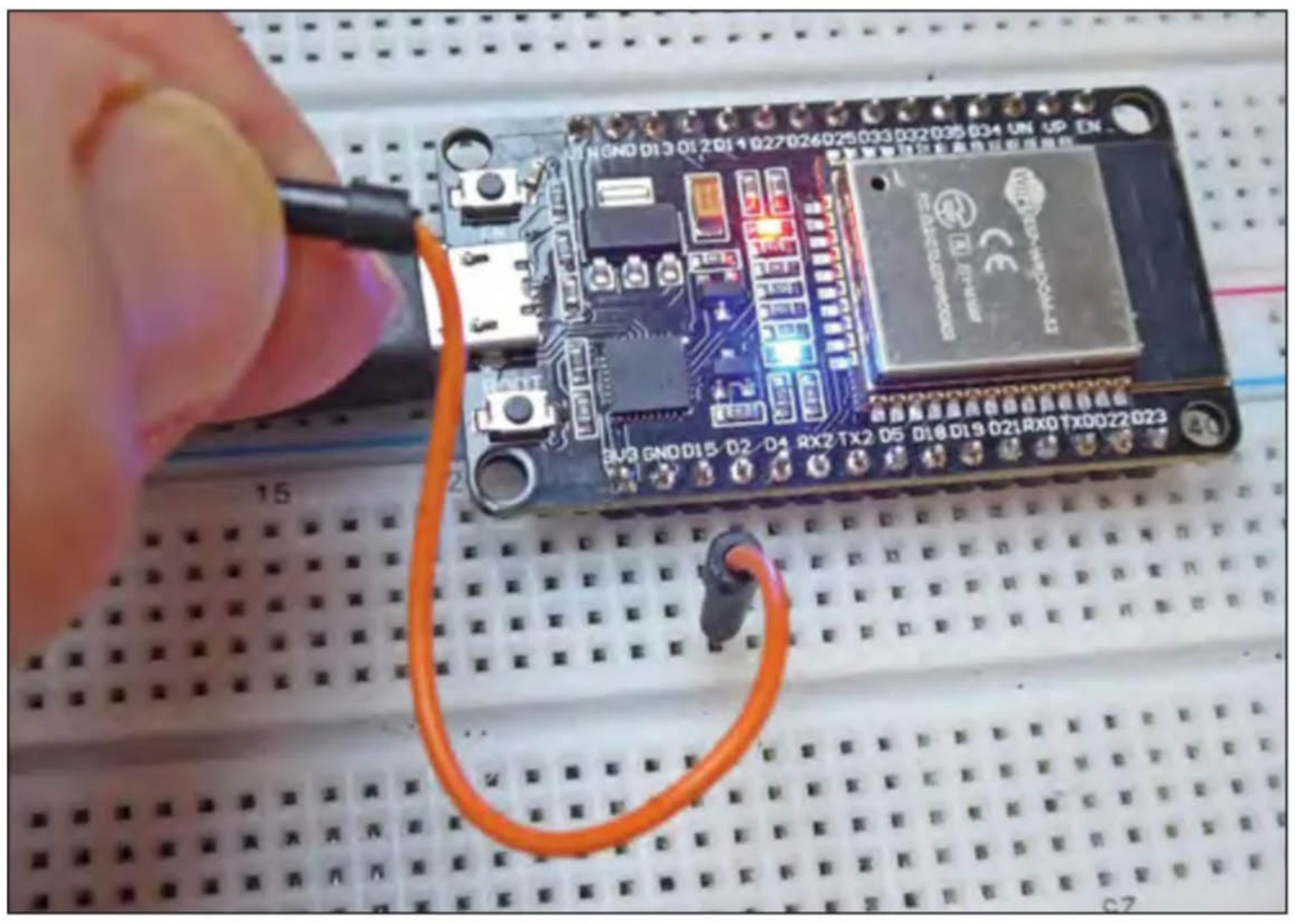


Fig.1.17. The on-board LED should operate when touching a jumper lead connected to GPIO15 (D15 on most boards).

Listing 1.1 Test code that flashes the ESP32's on-board LED

```
/* Flash the built-in LED via GPIO2 */
int ledPort = 2;      // ESP32 built-in LED
int timeOn = 200;     // On time (ms)
int timeOff = 800;    // Off time (ms)

void setup() {
  // Initialise the LED port as an output.
  pinMode(ledPort, OUTPUT);
}

void loop() {
  // This loop runs forever!
  digitalWrite(ledPort, HIGH);  // Turn the LED on
  delay(timeOn);
  digitalWrite(ledPort, LOW);   // Turn the LED off
  delay(timeOff);
}
```

Gotcha!

If you receive a message of the form 'A fatal error occurred: Failed to connect to ESP32' check first that you have the correct board and port selected. If that doesn't solve the problem, wait for the IDE's 'Connecting….' message to appear then press and hold the BOOT button until the next message confirming that the connection has been made, at which point the flash memory will be erased and rewritten. This can be tedious, but it usually works.

than a breadboard and jumper wire). Ten of the ESP32's GPIO pins can be configured as capacitive touch sensitive inputs. Simply placing a finger on one of these pins is sufficient for an input to be generated. This can be a great way of replacing pushbuttons and toggle switches. You can check this out using the code in Listing 1.2.

Enter (or download) the code shown in Listing 1.2 and then execute it in the same way as before. The user LED on GPIO2 should become illuminated whenever you touch a jumper lead connected to GPIO15 (see Fig.1.17).

Coding workshop

To get your hardware to do something useful you will need to have some code that will tell it what to do and how to respond when something happens. The process of producing code (ie, 'coding') is not particularly difficult but it does require a structured and systematic approach. If you've ever had to provide someone with a detailed set of instructions for travelling somewhere you will know how important it is not to forget any steps and to give your instructions in a clear

Listing 1.2 Code for checking the ESP32's in-built capacitive touch sensing inputs

```
/* Checking out the ESP32's touch sensors */
int ledPort = 2;   //ESP32 built-in LED

void setup() {
  // Initialise the LED port as an output
  pinMode(ledPort,OUTPUT);
  }

void loop() {
  // This loop runs forever
  delay(100);   // Wait for 100ms
  if (touchRead(15)<40)         // Touch!
  {
    digitalWrite(ledPort,HIGH); // LED on
  }
  else if (touchRead(15)>=40)   // No touch
  {
    digitalWrite(ledPort,LOW);  // LED off
  }
}
```

and unambiguous way. The same applies to computer coding, but with the added complication that we need to present our instructions in a way that can be interpreted by a machine rather than a human being. Coding is easy to learn if you 'start simple' and build up your skills progressively and systematically. We start this month with a look at the ways in which data is handled and manipulated.

Boolean data

Data that can only take one of two possible values is referred to as 'Boolean data'. Inside the Arduino this type of data can be represented using a single byte (8-bits) of data and it can take a value of either TRUE or FALSE, HIGH or LOW or simply 'on' and 'off'. These two states are mutually exclusive and we refer to them as 'Boolean' because they conform to the rules of Boolean Logic (much more of this in a later instalment).

The variables that we use in our code need to be declared before they can be used. An example of a Boolean declarations is as follows:

```
boolean powerGood = FALSE;    // power status
```

At some later point in the code (within the main loop that executes forever) you might encounter the following line:

```
powerGood = !powerGood;    // toggle the power status
```

Note that the '`!`' in the foregoing code fragment can be read as 'not' and the line of code simply changes the state of the Boolean variable to the opposite of what it was before. In other words, if `powerGood` had previously been HIGH it will now become LOW, and vice versa.

Unfortunately, there's some potential for confusion here. The Arduino uses a byte (8-bits) of memory to store Boolean data, but since Boolean data can only exist in one of two possible states and where available memory is limited (as it is with the Arduino) it would be advantageous to use just a single bit of data rather than an entire byte because seven of the eight bits used to store the Boolean data are just not being used (a stored binary value of 0000000 will be interpreted as FALSE and anything else will be interpreted as TRUE). This is rather wasteful and so it's important to remember that using a Boolean data type is no more efficient in terms of memory usage than using integer values (see later). That said, it can often be neat and convenient to use Boolean data types.

Integer data

Whole numbers (ie, numbers with no decimal point) are frequently stored as integers (or 'ints'). Integers require two bytes (16 bits) of storage and the most significant bit (MSB) is used to indicate the sign of the number. When this bit is 0 the value is positive and when it is 1 the value is negative. The method of representing numbers is referred to as '2's complement' notation and with 16-bits of data it yields a range that extends from –32768 to +32767. A typical extract from a program's setup code might be:

```
int powerLED = 11;    // Output pin used for the
                        power good LED
```

This line of code defines and initialises a variable that we've named `powerLED`. We've told the Arduino that it is to be handled as an int (ie, an integer) and that it is to be given an initial value of 11. The statement ends with a semicolon (`;`) and this is followed by a brief comment designed to act as a reminder of what the purpose of the statement is. Brief comments like this can be invaluable later on when the time comes to do some software maintenance and also when code is shared among several authors.

Later on in the program code you might find a line that takes the form:

```
digitalWrite(powerLED, HIGH);   // Illuminate the
                                  power good LED
```

Even if you've never done any coding before you can probably make a reasonable guess of what this statement does. At another point in the code you might find something like this:

```
if(powerGood = = FALSE) {
   digitalWrite(powerLED, LOW);
}
```

The above code fragment turns the 'power good' LED off when the system has sensed a problem with the power supply. It does this by examining the state of the `powerGood` Boolean variable (see earlier) and, if found to be FALSE (in other words, not good) the 'power good' LED is turned 'off' by writing a low (0V) to its digital output pin (pin-11 as defined within the integer declaration earlier in the code).

The syntax for the declaration (in this particular case it's a constant rather than a variable) is simply the name followed by the value that you've assigned to it. Note that the name takes the form of a meaningful description (two words with *no* space included between them). Note also that the first word begins with a lower-case character and the second word with a single upper-case character. This convention helps make the code easier to read and it avoids the need to include a space character in the name (which would be invalid).

At some point later in the code you might find something like this:

```
if(powerGood = = FALSE) {
  digitalWrite(powerLED, LOW);
}
```

There's often a need to increment or decrement a variable within a program loop (for example, when counting events) but, because of the use of 2's complement notation, it is very important to be aware that when a variable is incremented or decremented, the variable will roll-over whenever it reaches the maximum allowable size. So, for example, incrementing 32767 (the maximum allowable *positive* value) will cause the value to become –32768 (note the change of sign). In a similar manner, decrementing a value of –32768 (the maximum allowable *negative* value) will cause a variable to take a new value of +32767.

Finally please be aware that the use of two bytes to store an integer is not consistent over all Arduino versions. For example, the Arduino Due uses four bytes (32-bits) to store integer values. This provides a range of values extending from –2,147,483,648 to +2,147,483,647.

Floating point data

As the name implies, floating point numbers, or 'floats', are numbers that include a decimal point. They offer a much larger range from –3.4028235E+38 to +3.4028235E+38. Floats are stored using four bytes (32 bits) of data.

Floats are often used to represent analogue values from sensors. Due to the need for four bytes of data, floating point mathematics can be significantly slower than when integers are used (where only two bytes of data are involved). Consequently, it is advisable to use integers rather than floats whenever speed of execution is important.

A typical extract from a program's setup code might be:

```
float peakConvert = 1.4159;    // To convert from
                                  RMS to peak
```

We could then determine the peak voltage and peak current present in a 50Ω load using something of the form:

Listing 1.3 Code for the portable emergency beacon

```
/* Listing 1.3 ESP 32 emergency beacon */
char message[] = “SOS”;
int ledPort = 2;             // ESP32 built-in LED
int dotLen = 100;            // length of a dot
int dashLen = dotLen * 3;    // length of a dash
int gap = dotLen * 5;        // length of a space

void setup() {
  pinMode(ledPort, OUTPUT);
}

void loop() {
  for (int i = 0; i < sizeof(message) – 1; i++) {
    char tempChar = message[i];
    GetChar(tempChar);
  }
  LEDOff(gap);  // Extra gap between repeats
}

// DOT
void MorseDot() {
  digitalWrite(ledPort, HIGH);  // LED on
  delay(dotLen);
}

// DASH
void MorseDash() {
  digitalWrite(ledPort, HIGH);  // LED on
  delay(dashLen);
}

// LED Off
void LEDOff(int holdTime) {
  digitalWrite(ledPort, LOW);  // LED off
  delay(holdTime);
}

// Morse code
void GetChar(char temp) {
  switch (temp) {
    case ‘S’:  // Three dots
      MorseDot();
      LEDOff(gap);
      MorseDot();
      LEDOff(gap);
      MorseDot();
      LEDOff(gap);
      break;
    case ‘O’:  // Three dashes
      MorseDash();
      LEDOff(gap);
      MorseDash();
      LEDOff(gap);
      MorseDash();
      LEDOff(gap);
      break;
  }
}
```

```
peakVoltage = rmsVoltage * peakConvert;
peakCurrent = peakVoltage / 50;
```

Byte data

Byte is used to store 8-bits of data as unsigned binary numbers. So, for example, a binary value of 10000001 (equivalent to 81 in hexadecimal or 128 in decimal) might be defined as follows:

```
byte bitMask = 0x81; // mask unwanted bits
```

Note that the ‘0x’ prefix denotes a value expressed in hexadecimal (base 16) format. Because only eight bits are used, byte data is limited in range. The minimum value that can be represented is 0 when all of the bits are 0 (hexadecimal 0x00) and the maximum value is 255 (hexadecimal 0xFF) when all of the bits are set to 1. Despite the restricted range, byte data can be useful in a variety of applications, particularly when dealing with the status of eight input or output lines. For example:

```
byte inputStatus = 0x00;    // initialise input
                               port status
byte inputFailure = 0xFF;   // all port lines
                               have gone high
```

At some later point in the code, we might encounter a line of the form:

```
if(inputStatus = = inputFailure) {
   Serial.print(“Warning: Input failure!”);
}
```

In this example a fault is present if all of the input lines are simultaneously in the HIGH state and in this condition the value of the `inputStatus` variable will be 0xFF. If this condition is detected a brief warning message will be sent via the serial port (more of using the serial monitor later in the series).

Character data

The character data type is used when we just need to represent alphanumeric information such as plain text. The character data type uses a single byte of memory to store each character. Thus, the word ‘character’ would need nine bytes of storage. Character literals are enclosed within single quotes (eg, ‘A’), while double quotes are used for strings comprising several characters (eg, “Power Good”).

Character data is encoded using the American Standard Code for Information Interchange (ASCII). Each character is represented by a corresponding signed 8-bit value. ‘A’ for example is encoded as 01000001 in binary. This is equivalent to 41 in hexadecimal or 65 in decimal. The basic ASCII character set uses only seven bits (equivalent to a decimal range that extends from 0 to +127. When the leading bit is set (ie, 1 and not 0) the signed byte becomes negative with a range extending from –1 to –128. These 128 values can be used to represent special characters. Note that the following three lines of code are equivalent:

```
char testChar = ‘A’;
char testChar = 65;
char testChar = 0x41;
```

Also note how the number base in the last example is indicated by the prefix `0x`, which indicates that the number that follows is written in hexadecimal format.

The `Serial.println()` function provides you with a way of printing data using several different representations:

```
Serial.println(analogValue);         // print as
                              ASCII-encoded decimal
Serial.println(analogValue, DEC);   // print as
                              ASCII-encoded decimal
Serial.println(analogValue, HEX);   // print as
                              ASCII-encoded hex
Serial.println(analogValue, OCT);   // print as
                              ASCII-encoded octal
Serial.println(analogValue, BIN);   // print as
                              ASCII-encoded binary
```

This concludes our brief look at the way that data is represented. Next month we will be getting to grips with some data manipulation.

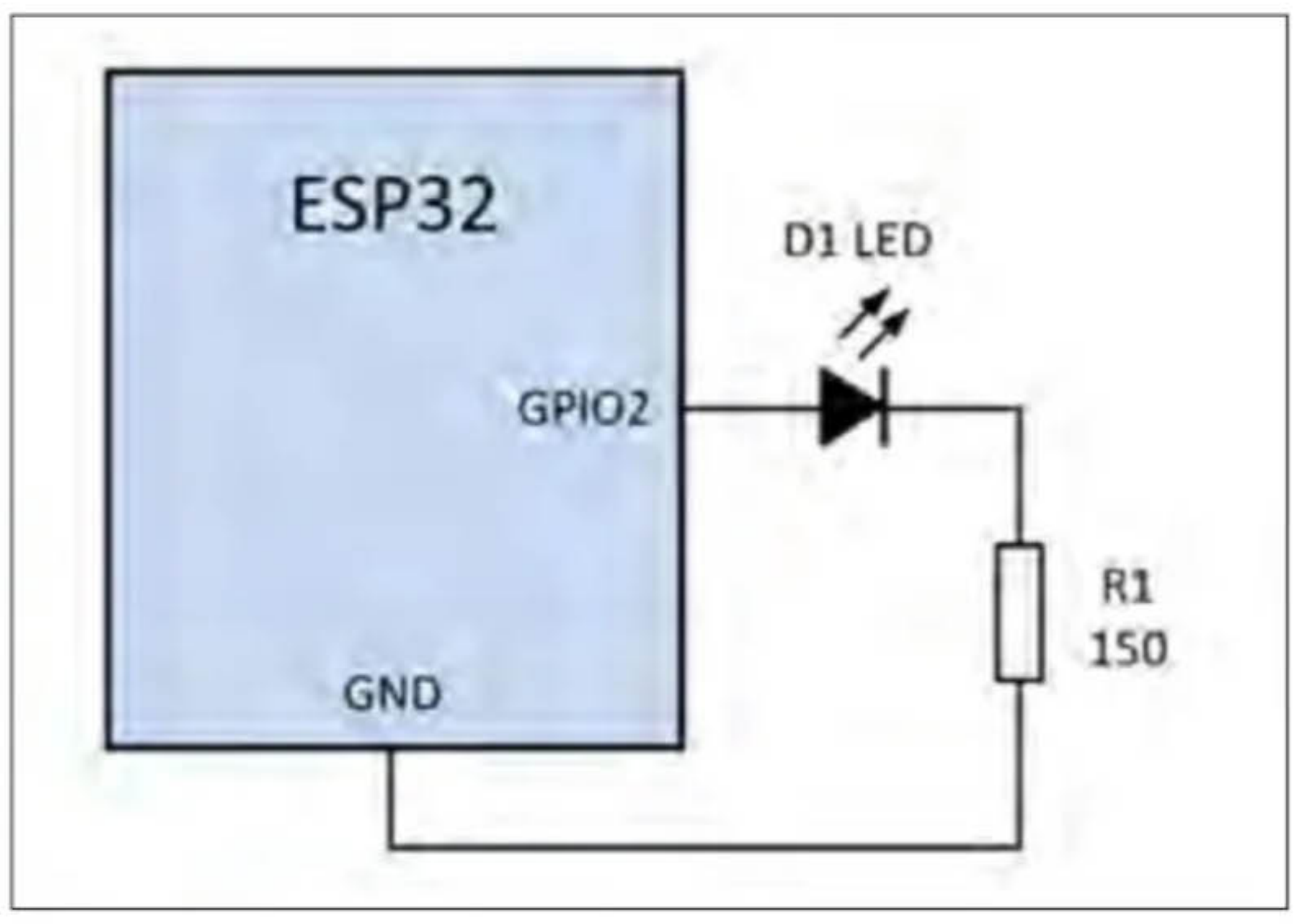


Fig.1.18. Off-board circuit for the prototype emergency beacon.

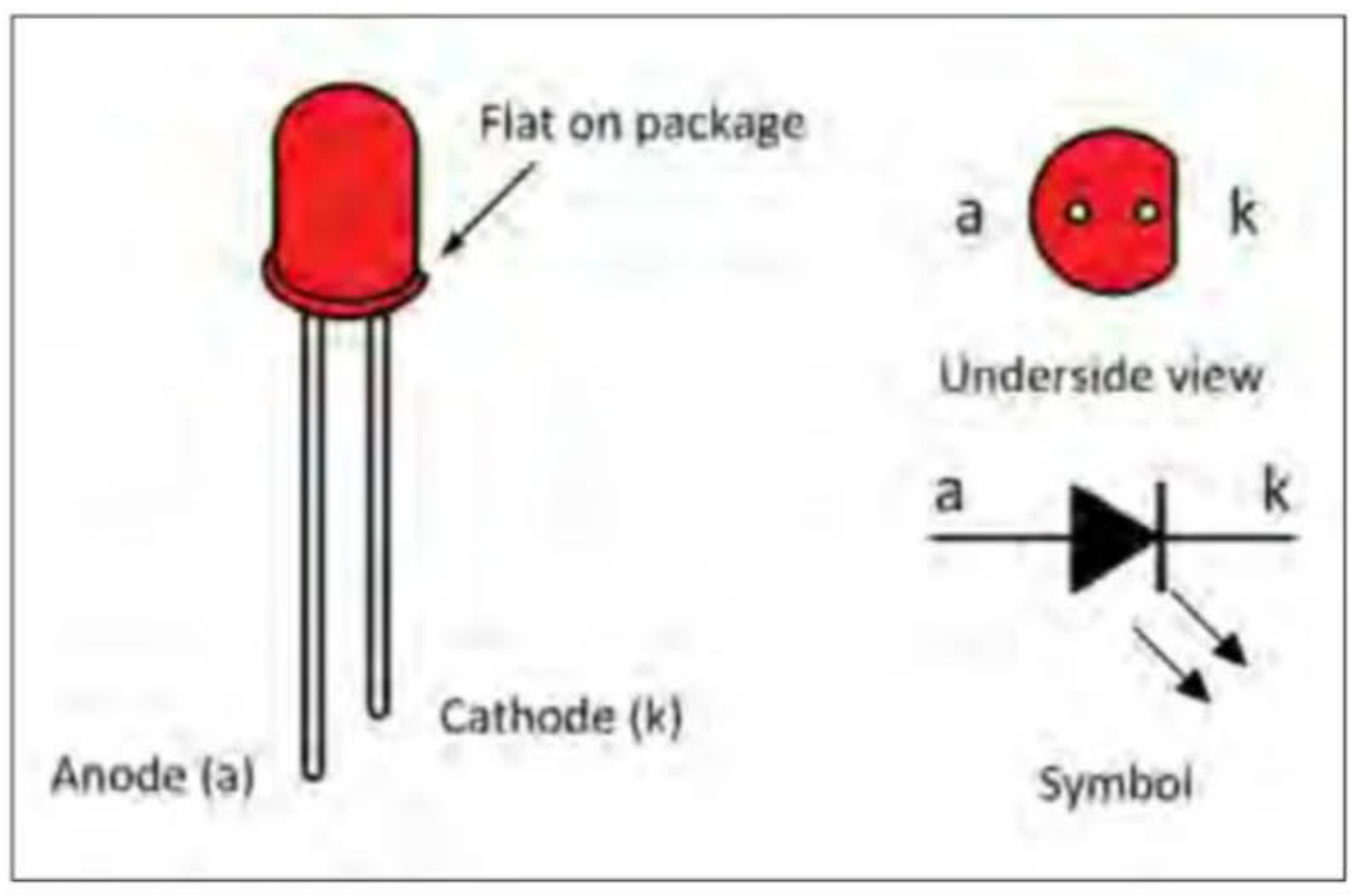


Fig.1.21. LED pin connections.

Practical project

Our first practical project involves the design, construction, and coding for a simple portable emergency beacon. We will develop the circuit using an ESP32 Devkit and development board. The finished version could use an ESP32 module, a high-intensity LED and a rechargeable battery, but for now we will do the development using a standard Devkit, LED and USB power from the host computer.

The minimal circuit and wiring layout for our prototype emergency beacon are shown in Figs.1.18 to 1.20. The pin connections for the LED are shown in Fig.1.21. (Note that it is important to connect LEDs with the correct polarity.) The 150Ω resistor is used to set the current that will be supplied to the LED (in this case about 7mA).

Having connected the circuit, made the USB connection to your PC, and started the IDE, you can enter (or download) the code shown in Listing 1.3. When you run the code, you should see the LED repeatedly flashing an 'SOS' message in Morse code.

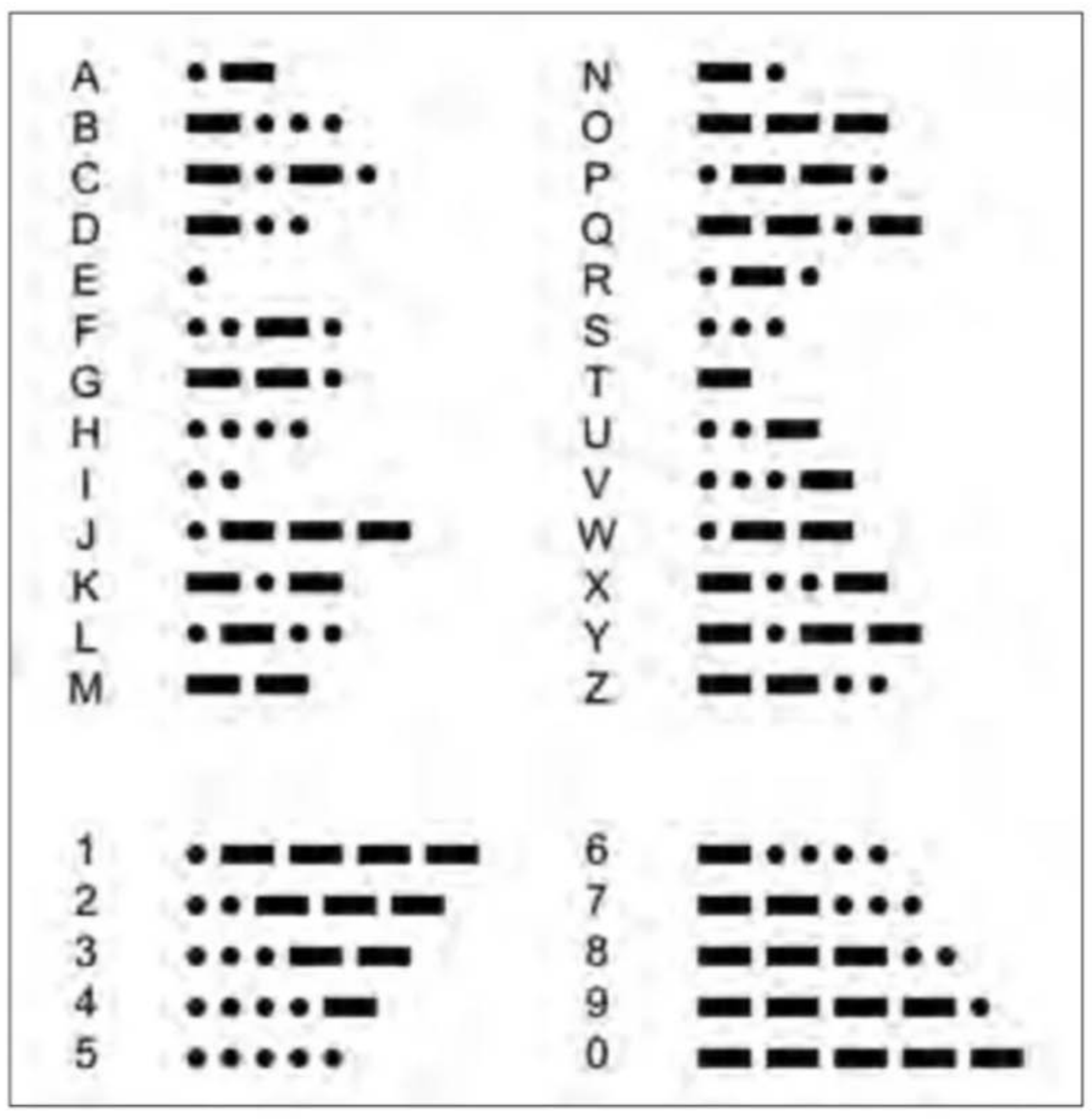
Now let's walk through the code. The first few lines of code define the variables (explained earlier). Note that we have the `dashlen` and `gap` variables in terms of the `dotlen` variable that was previously defined. Thus, to change the speed of the Morse code beacon we only need to change `dotlen` and the other two variables will change in proportion.

Next, we enter the main loop which examines each character in our `message` in turn and determines the pattern of dots and dashes that represent the character in Morse code (see Fig.1.22). If a dot is required, the LED is switched on (`ledPort` goes HIGH) for a time defined by `dotlen` before being switched off for a time defined by `gap`. Alternatively, if a dash is required, the LED is switched on (`ledPort` goes HIGH) for a time defined by `dashlen` before being switched off for a time defined by `gap`. Note that the voltage present at a GPIO pin voltage will be approximately 3.3V when in the HIGH state and 0V when in the LOW state. Thus, when our code takes GPIO2 HIGH current will begin to flow in the LED and it will become illuminated. Conversely, the current will stop when GPIO2 is taken LOW. This allows us to switch the LED on and off.

Don't worry if you don't fully understand the code at this stage. The most important thing to grasp for now is how the GPIO pins are controlled through `digitalWrite()`. We will be taking a more detailed look at this when we explain digital I/O next month.

Teach-In challenge

Our *Teach-In* challenges will provide you with something to test the knowledge that you've acquired. This month, starting with the emergency beacon code that we met earlier, modify and extend the code so that it continuously flashes a 'HELLO' message in Morse code.



A	•—	N	—•
B	—•••	O	———
C	—•—•	P	•——•
D	—••	Q	——•—
E	•	R	•—•
F	••—•	S	•••
G	——•	T	—
H	••••	U	••—
I	••	V	•••—
J	•———	W	•——
K	—•—	X	—••—
L	•—••	Y	—•——
M	——	Z	——••
1	•————	6	—••••
2	••———	7	——•••
3	•••——	8	———••
4	••••—	9	————•
5	•••••	0	—————

Fig.1.22. Morse code.

> ### Gotcha!
> Code can be pretty darn picky and unforgiving! Common errors are forgetting to end lines with '`;`', not terminating a multi-line comment with '`*/`' and failing to pair opening and closing braces, '`{`' and '`}`'. As time goes on you will undoubtedly become proficient and learn to avoid these basic errors.

Next month

In the next part of our *Teach-In* series We will take a close look at digital input and output. We will provide a detailed look at the relationship between digital signals and logic levels, and explain how the GPIO ports are configured. We will learn how to interface buttons and switches, and develop simple code to sense and display their state. *Coding workshop* will introduce logical constructs and decision making. We will also introduce flow charts, and explain the design and construction of a simple traffic light controller.

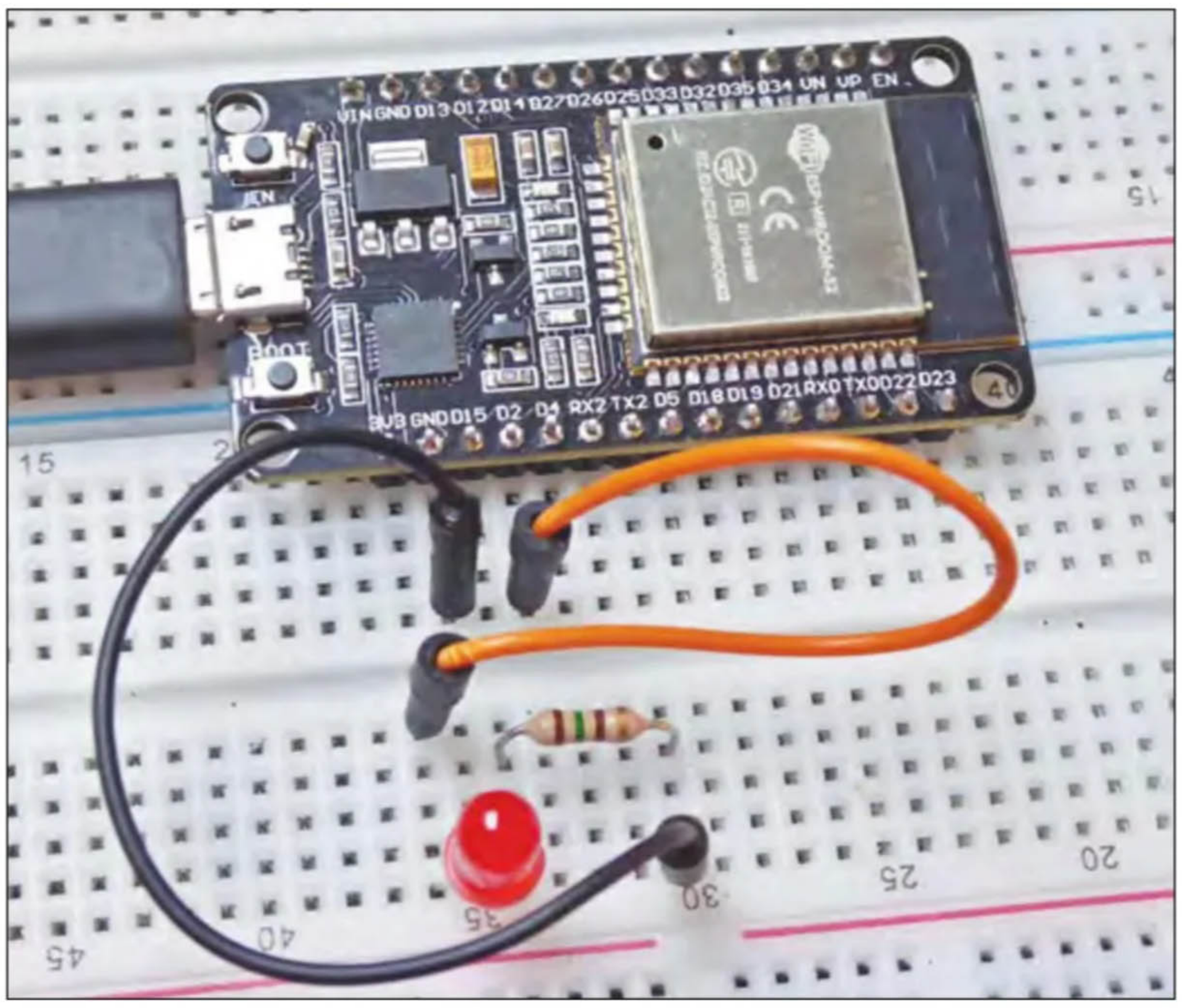


Fig.1.19. Wiring for the prototype emergency beacon based on a 30-pin board.

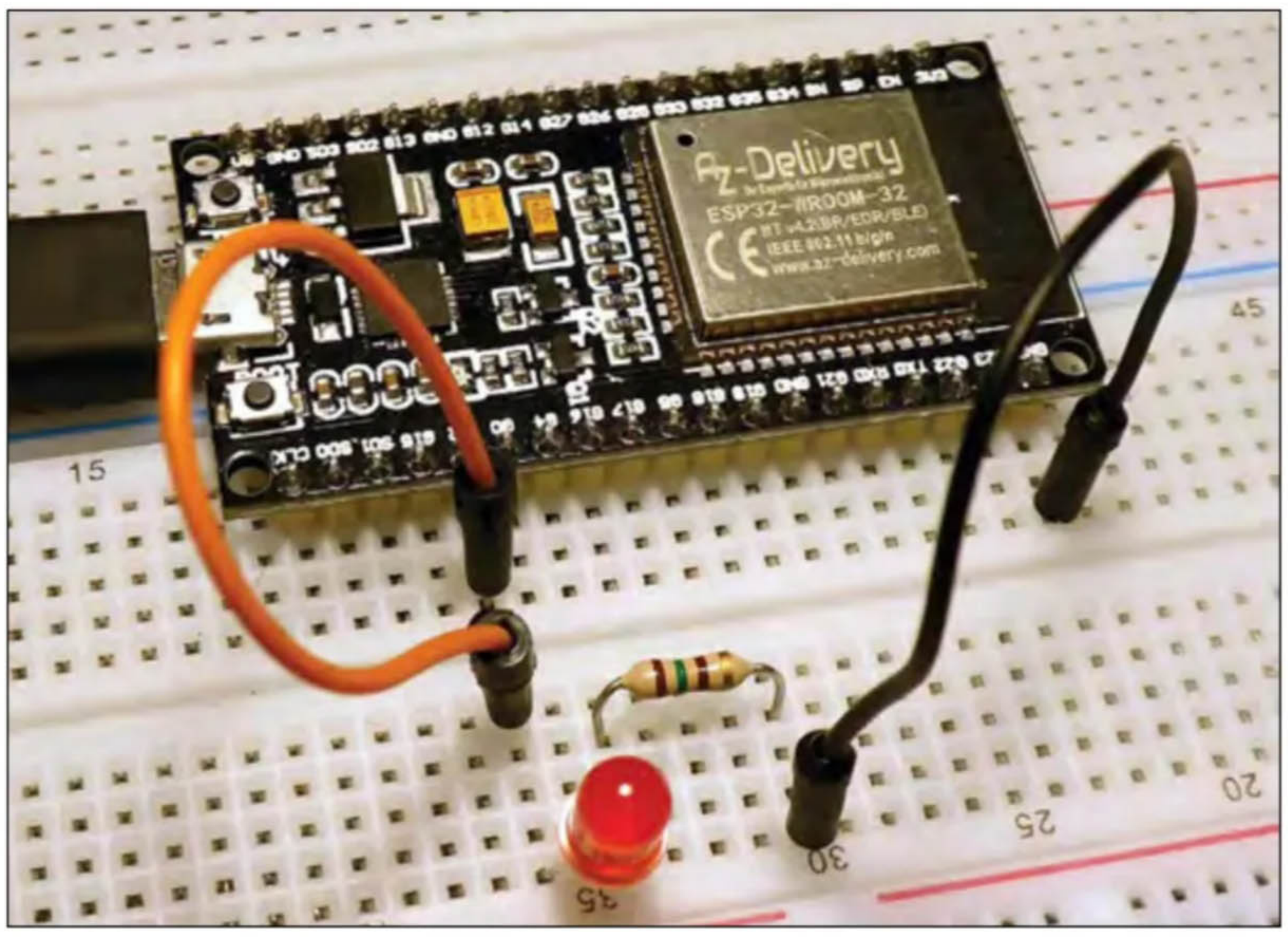
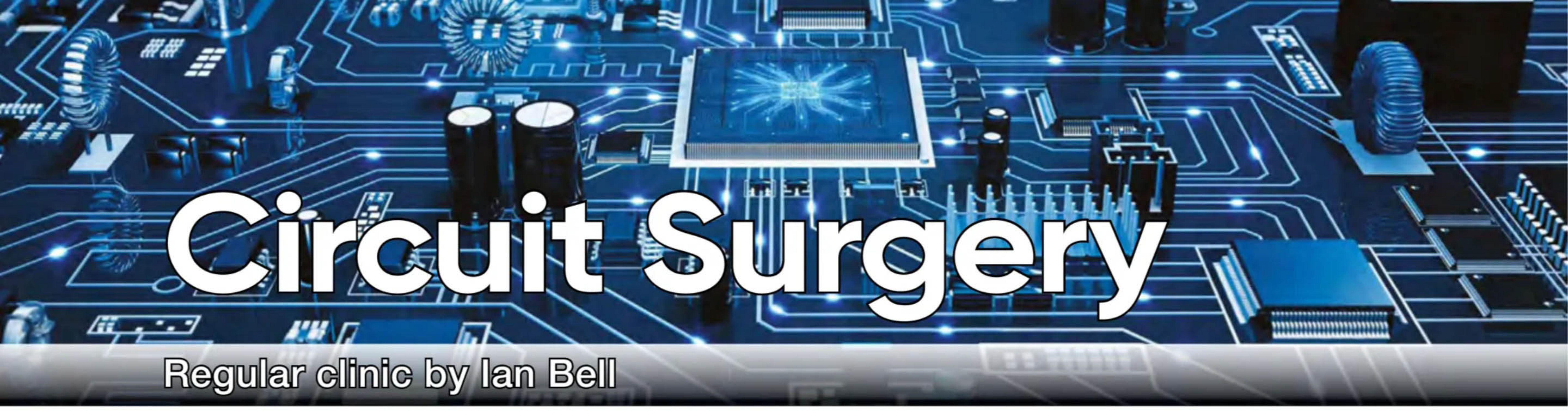


Fig.1.20. Wiring for the prototype emergency beacon based on a 36-pin board.



Circuit Surgery

Regular clinic by Ian Bell

LTspice 17.1 and Frequency Response Analysis – Part 1

Regular readers will know that *Circuit Surgery* regularly uses LTspice simulations to illustrate circuit operation and behaviour. LTspice was developed by Linear Technology and was originally also referred to as 'SwitcherCAD' because of its optimisations for simulating switching regulators and related circuits, which were a key Linear Technology product line. In 2017, Linear Technology became part of Analog Devices, who took over LTspice. The LTspice download is provided with a library of models of real components. Initially, these were for LT devices, but of course Analog Devices' components were added after the merger. Another merger of Maxim Integrated into Analog Devices means their devices have been added too. Models for devices from other manufacturers (mainly passive components and transistors) are also included.

LTspice updates it model library regularly and there are also minor software updates, such as bug fixes, but there have not been major software updates for some time. Version 17.0 (written as 'LTspice XVII') dates from 2016. In 2023, Analog Devices released LTspice 17.1, which it described as a significant upgrade to LTspice XVII. The key addition was a new frequency response analyser component and an associated `.fra` spice directive, which we will discuss in detail later. However, there are a few other changes that we will mention first.

Download and install

LTspice 17.1 can be downloaded for free from the Analog Devices website: **https://bit.ly/pe-jan24-ltspice**

It is available for Windows 10 64-bit and forward, and MacOS 10.15 and forward. The older version is still available too. LTspice 17.1 can be installed alongside LTspice XVII since both the executables and models for the two versions are stored in different locations. You can run both apps at the same time but must not open the same file in both versions at the same time.

Visually, the user interfaces look very similar, although user interface improvements and bug fixes are listed as enhancements. The new version is named simply 'LTspice', not 'LTspice XVII' in the application title bar and desktop icons. If you want to use both and would like a more obvious visual indication, you could try changing the background image which appears in the background behind schematic and waveform windows (Control Panel> Operation > Background Image).

Downloading and installing LTspice 17.1 is straightforward. During the install it asks if the installation is just for the current user or for everyone – this changes the default install location. On Windows, installed examples and libraries are always stored in the current user's local application data folder (C:\users\[User]\AppData\Local\LTspice\) rather than in the documents folder (C:\Users\[User]\Documents\LTspiceXVII) that was used by the previous version. If you have custom libraries or symbols in the old location then you could copy them to the new location or use the control panel (Tools > Control Panel > Sym. & Lib. Search Paths) to add the location of your custom folders to the search path used by LTspice.

Other enhancements

The new version has improved the drawing speed of the waveform viewer when plotting large amounts of data. This was definitely a problem with the previous version, where, for example, just resizing the waveform viewer window could result in a lengthy redraw period (this is just drawing the waveform, not running the simulation). This can be observed with some of the simulations in the recent superhet receivers *Circuit Surgery* articles where the data sets were large because relatively long simulations were used to obtain enough data for LTspice to accurately plot the signal spectra. As a quick test I resized the full results (all key waveforms shown in separate plot panes) and the speed-up was obvious, with one example taking around 20 to 30 seconds to redraw in the old version, but only 2 to 3 seconds in LTspice 17.1.

Another enhancement is that keyboard shortcuts can now be saved to and loaded from text files. Previous LTspice allowed changes to keyboard shortcuts, but there was no easy way to export these settings so that they could be used in another instance of LTspice (eg, to use on another computer or share with another user). This is now straightforward to do via the Control Panel, with the shortcuts stored in a human-readable text file.

Finally, Analogue Devices also lists some improvements to the simulator operation, specifically: fixed convergence problems, updated initial conditions behaviour and reduced multi-threaded CPU loading.

Frequency response analysis

LTspice's frequency response analysis (FRA) is aimed at determining the behaviour of negative-feedback loops. All feedback systems have the potential to become unstable and oscillate, which is often disastrous (unless you are building an oscillator!). The FRA is aimed at determining the stability of negative-feedback circuits; that is, finding out how much margin of error you have between stable and unstable operation. If the margin is too low the circuit may become unstable in use due to changes in conditions (temperature, supply voltage, component tolerance, aging and so on).

The LTspice FRA is (currently) optimised for use with switch mode-powers supplies (SMPS), but it can be used with other feedback circuits – however, the set-up and analysis provided may not be so convenient for non-SMPS scenarios. A comment on Analog Devices' forum indicates that a new version may improve this situation soon.

To introduce the basic ideas behind and the use of the FRA, we will look at simple op amp circuits rather than dealing with the complexities of a SMPS – the FRA can certainly be used in this context because an op-amp-based example is provided as part of the LTspice 17.1 download. To appreciate the use of the FRA it is necessary to understand the principles of negative feedback and stability. Therefore, before looking at the LTspice FRA in detail we will introduce the basics of negative feedback and stability in the context of standard, well-known op amp amplifier circuits.

Op amp basics

The output (V_O) of an op amp (see Fig.1) without any additional external components is given by: $V_O = A_O(V_1 - V_2)$.

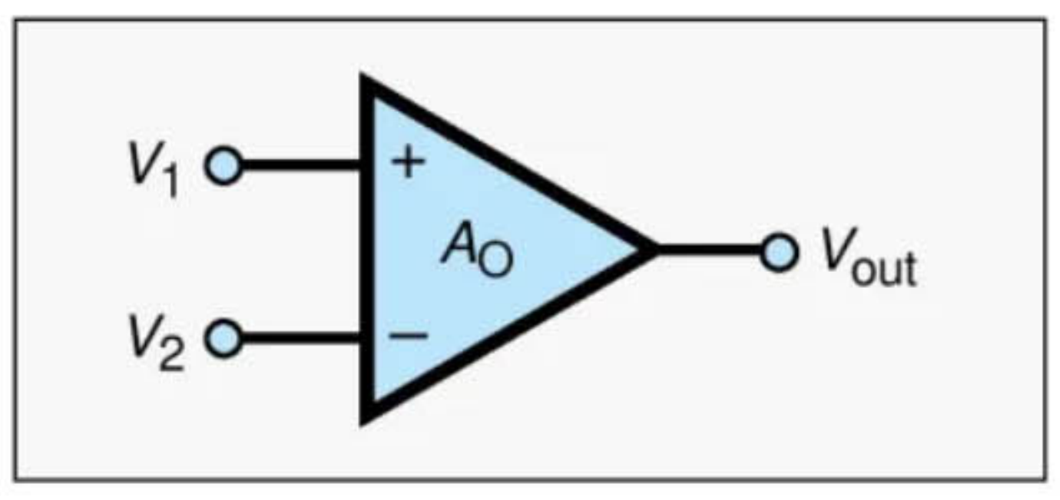


Fig.1. Open-loop op amp.

Here, V_1 is the voltage on the non-inverting input, V_2 is the voltage on the inverting input and A_O is the open-loop voltage gain, which is specified on a device's datasheet and is typically in the range 70 to 150dB (approximately 3000 to 30 million). For an 'ideal' amplifier, open-loop gain tends to infinity. An op amp amplifies the voltage *difference* between its two inputs ($V_1 - V_2$), *not* the voltage with respect to ground at a single point.

Op amps are usually used with negative feedback – a fraction of the output signal is fed back and subtracted from the input – it is applied at the inverting input to achieve the subtraction. This creates a loop from the output back to the input and then to the output again – hence the term 'feedback loop' and why the gain of the op amp device on its own is referred to as 'open-loop gain' (gain when the feedback loop is open, or not connected). The gain of the whole circuit with feedback is called the 'closed-loop gain' (A_C).

The most basic and commonly used op amp amplifier circuits in which negative feedback is applied are the inverting or non-inverting amplifier configurations, as shown in Fig.2. In both cases the negative feedback is applied via a pair of resistors which act as a potential divider feeding a fraction of the output voltage back to the inverting input. The gain of these circuits is therefore related to the ratio of the resistor values, which sets the proportion of the output fed back by the potential divider. The amplifier as a whole is either inverting (negative gain) or non-inverting (positive gain) depending on whether the input signal is routed to the inverting or non-inverting input.

In an op amp amplifier, the negative feedback is regulating/controlling the differential input voltage to the op amp to be zero. The differential input to the op amp is a function of the circuit input minus the feedback. If the input voltage to the circuit changes the op amp output changes until the subtraction of the feedback reduces the voltage across the op amp's inputs to zero. Thus, the output voltage will track changes in the circuit's input voltage in a manner determined by the feedback, while keeping the voltage across the op amp's inputs zero.

As can be seem from the examples in Fig.2, the gain equations for the amplifier as a whole only depend on the resistor values. Strictly speaking these formulae are approximations, but if the op amp's open-loop gain is much larger than the overall circuit gain the approximation is very good. The gain of the op amp itself does not change when we apply feedback – it is the gain of the whole circuit which is determined by the feedback. In fact, the input-output relationship of the op amp remains exactly as given in the equation above when the feedback is in place. This implies the input voltage difference is actually V_{out} / A_O, not zero as in the preceding discussion. However, as with the representation of circuit gain with the resistor formula, the approximation to zero input difference is very good for op amps with very high open-loop gain.

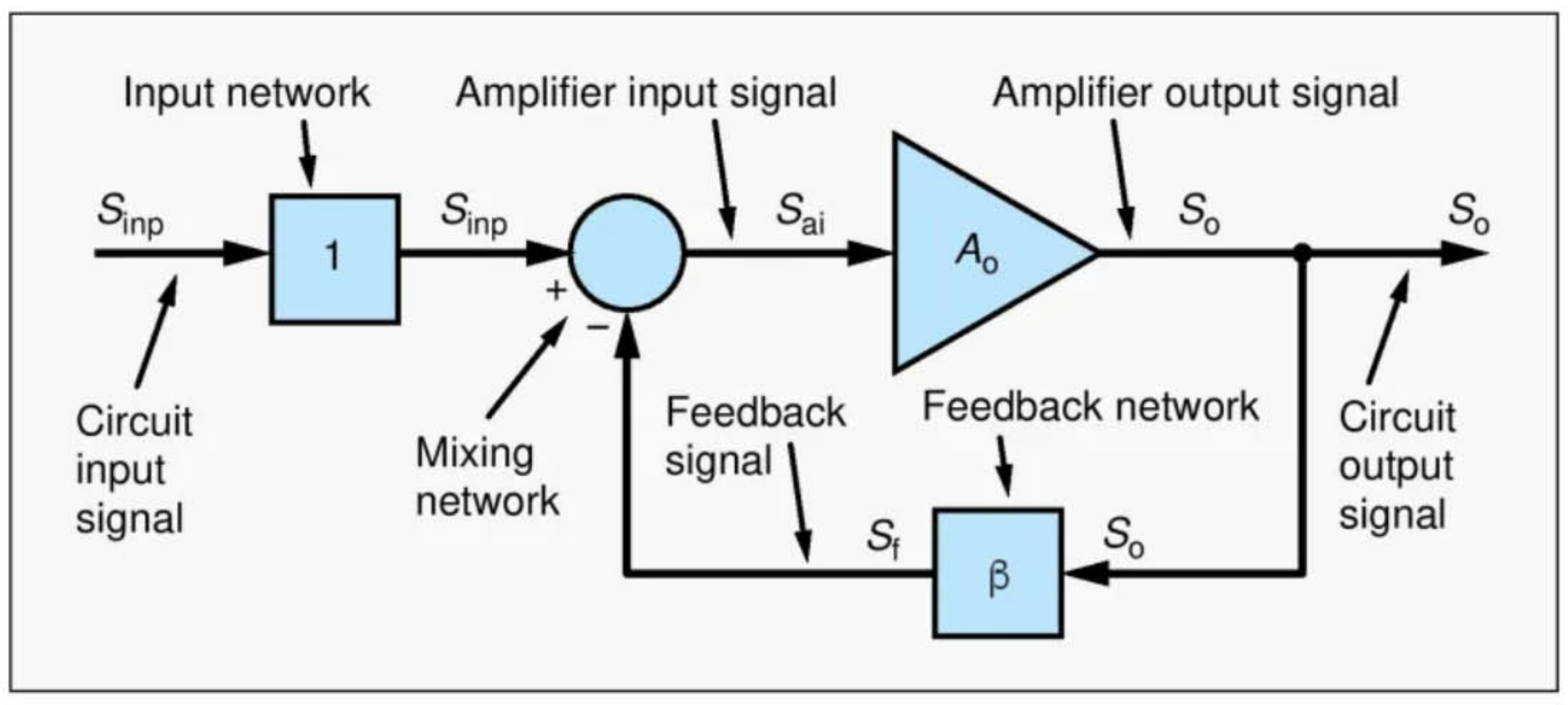


Fig.3. Example structure of an amplifier with negative feedback. Note: this is specifically the non-inverting op amp amplifier.

Feedback structure

An abstract diagram of the structure of an amplifier with feedback is shown in Fig.3. This a system structure diagram, not a circuit schematic. Such diagrams are widely used by control engineers when developing systems (eg, in industrial control) that are a lot more complex than an op amp circuit.

In the context of an amplifier, the signals (labelled S) could be either voltages or currents. In general, the input signal (S_{inp}) may pass through an input network, as shown, which in the simplest case just multiplies the input by one – for example, in the non-inverting op amp amplifier the input goes straight to the op amp. For the inverting op amp amplifier, the resistors form a potential divider for the input signal, so the input network is not simply unity gain.

The input signal then passes to the mixing network, which subtracts the feedback (S_f) from the input. This is performed by the op amp, and in the case of the inverting amplifier, the 'summing junction' combines signals at the inverting input. The amplifier block in Fig.3 represents the open-loop gain of the op amp.

The feedback is obtained from the output of the amplifier by passing it through the feedback network (resistor potential divider in the op amp amplifiers) which multiplies it by a factor of β, so $S_f = \beta A_O S_{ai}$. (β is known as the feedback factor and is typically less than or equal to one.)

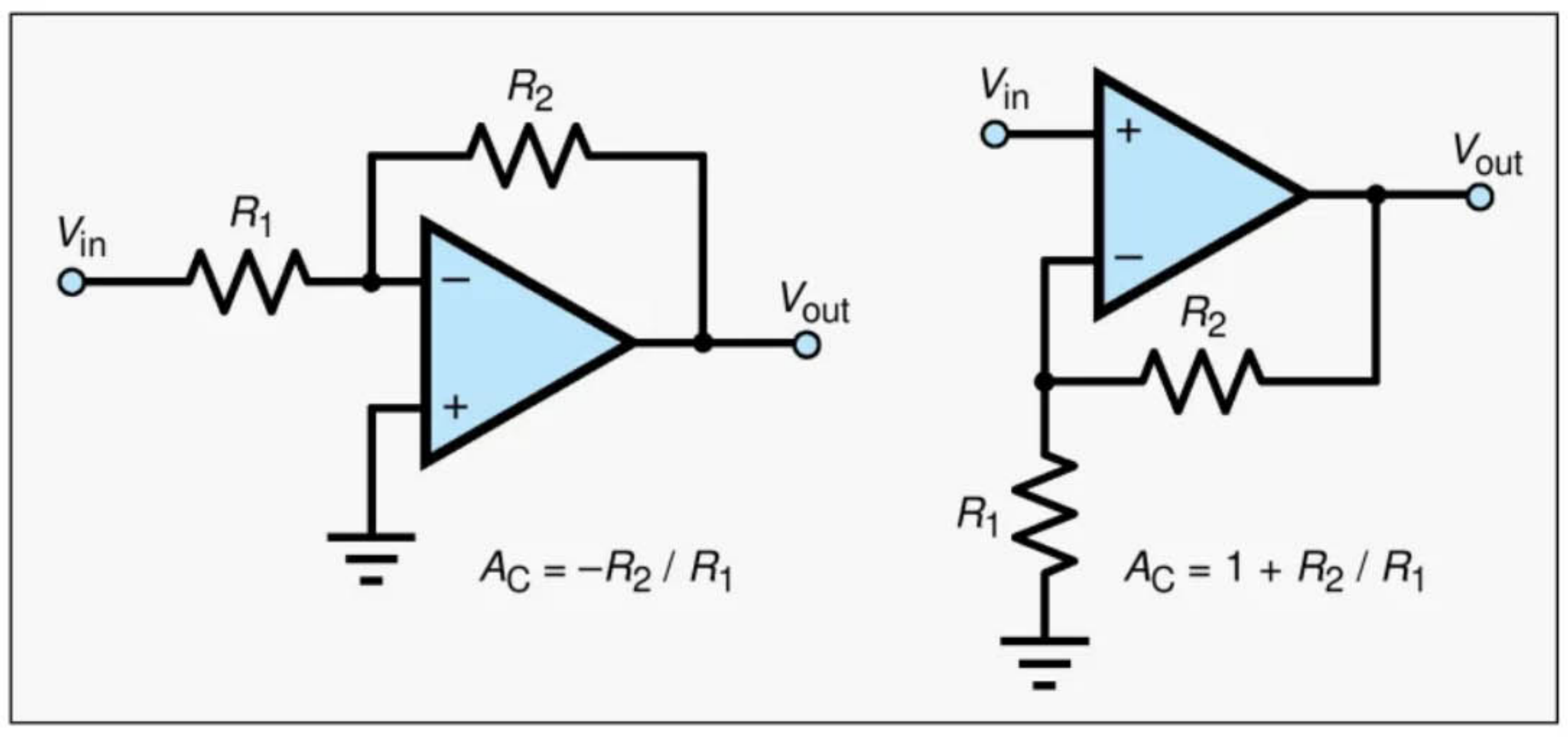


Fig.2. Op amp amplifiers.

We have three different gain values which can be used when discussing the amplifier with feedback. These relate to the three paths in the circuit depicted in Fig.4. First, the amplifier on its own has an open-loop gain of $A_O = S_O/S_{ai}$. Second, the whole circuit (amplifier with feedback) has a closed-loop gain of $A_C = S_O/S_{inp}$. Finally, the value $-\beta A_O$ is known as the 'loop gain', which is the gain around the closed feedback loop.

Gain calculations

Referring to Fig.3 we can calculate the closed-loop gain in terms of the open-loop gain and feedback factor. The feedback signal is the output multiplied by the feedback fraction (βS_O). Subtracting the feedback signal from the circuit input gives the amplifier input as:

$$S_{ai} = S_{inp} - \beta S_O$$

The amplifier (and circuit) output is the amplifier input multiplied by the amplifier open-loop gain:

$$S_O = A_O S_{ai}$$

Substituting for S_{ai}:

$$S_O = A_O S_{inp} - \beta A_O S_O$$

Collecting the output terms together gives:

$$S_O + \beta A_O S_O = A_O S_{inp}$$

And rearranging to find the closed-loop gain, we get:

$$A_C = \frac{S_o}{S_{inp}} = \frac{A_O}{(1 + \beta A_O)}$$

In a typical op amp amplifier A_O is very large and β is a moderate fraction so βA_O is usually much larger than 1 and we can approximate $(1 + \beta A_O)$ to βA_O. This means that the instances of A_O cancel in the A_C equation to give:

$$A_C = \frac{A_O}{\beta A_O} = \frac{1}{\beta}$$

This leads to the situation discussed above, where the op amp amplifier's gain is set by the feedback resistors (which determine β), independent of the op amp open-loop gain (as long as βA_O is much large than one).

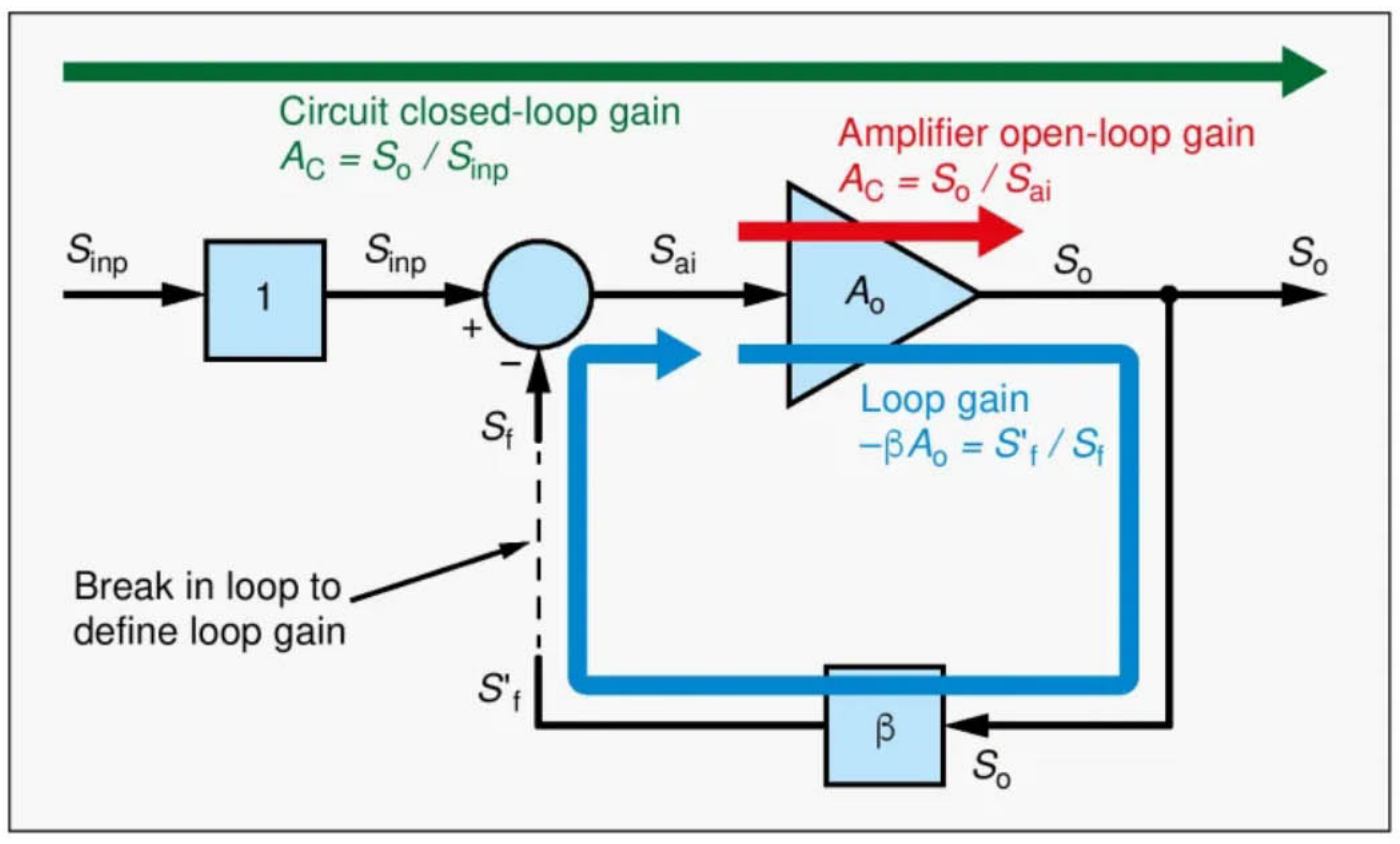


Fig.4. Structure of an amplifier with negative feedback showing the open-loop (red), closed-loop (green) and loop-gain (blue) relationships.

Loop gain

The loop gain is an important parameter when considering the stability of feedback systems.. By definition, the start and the end of a loop are the same point, so if we write the loop gain simplistically this way, say, S_O/S_O, we just get 1. We can *define* loop gain by breaking the loop, as shown in Fig.4. This allows us to obtain two different signals S_f and S'_f which are really at the same point in the loop giving a gain for the complete open-loop path as S'_f/S_f, which does not cancel to 1. We trace the entire path of the loop in the system diagram from, and back to, the break, so it does not matter where the break is – we get the same expression for loop gain. For the circuit in Fig.4, the loop contains three elements: the amplifier (gain A_O), the feedback section (gain β) and the negative summation (gain –1), so the loop gain for this system is these multiplied together, which is $-\beta A_O$.

We broke the feedback loop to help define loop gain, and in theory it may be possible to break the loop of a feedback circuit for the purposes of simulation or measurement to find loop gain (we cannot measure loop gain directly from the original circuit voltages). However, breaking the loop and retaining enough 'normal' circuit behaviour to make a valid measurement is not straightforward – for example, the output driving the break may have to be loaded with the same impedance it sees in the normal circuit, and the DC conditions need careful attention so that the bias levels in the 'broken' circuit match those in normal operation. Often, it isn't possible to obtain meaningful results using a broken loop.

Measuring loop gain

There are a number of approaches to overcome this. For example, in simulation the correct DC levels can be achieved by inserting an extremely high-valued inductor instead of a pure open circuit. This effectively keeps the loop closed for DC (for which the inductor is a short circuit), preventing any small DC levels being open-loop amplified to cause the amplifier output to saturate at the supply levels. For AC signals this super-sized inductor has an extremely high impedance and effectively breaks the loop, allowing a simulation in which a test signal is injected to show the AC characteristics of the loop (ie, the frequency response of the loop gain). Unfortunately, this method does not give very accurate results.

Another approach was published by R. David Middlebrook, 'Measurement of Loop Gain in Feedback Systems', in the *International Journal of Electronics* in 1975. This uses test signals injected into the closed-loop system (in a simulation, voltage and current sources can be inserted in the loop). This allows (through the theory developed by Middlebrook) to find the voltage and current gains of the loop and combine these to find the loop gain. If the feedback loop includes a low impedance driving a high impedance at some point, then the current gain has minimal impact so just the Middlebrook voltage gain is equal to the loop gain. This 'voltage only' version of the Middlebrook method is used by the new LTspice frequency response analysis.

Phase shift

The output of a circuit does not respond infinitely quickly to changes at its input, so any signal fed back from the output to the input will be offset in time with respect to the original input. Phase shift represents the delay of a sinewave signal through a circuit at a given frequency. If the delay is constant then phase shift will increase linearly with frequency, but often this is not the case, particularly over wide frequency ranges.

Consider a simple case in which there is a fixed delay from input to output of the circuit whatever the input signal does (things are usually more complicated than this). Say, for example, this delay was 0.1µs. If the input frequency was 100Hz this time would be 0.001% of the signal's cycle time and could probably be considered insignificant. However, at 2.5MHz the 0.1µs delay is a quarter of the signal's cycle time of 0.4µs ($1/2.5\times10^6 = 4.0\times10^{-7}$). This would usually be expressed by saying that the circuit had a phase shift of 90° at 2.5MHz (one complete cycle of the waveform is 360°). At 5MHz 0.1µs is half the cycle time of the signal. This is a significant point because a phase shift of 180° is equivalent to multiplying the signal by –1.

Instability

Consider the total phase shift through the amplifier and feedback network (in Fig.3) as we increase the input signal frequency – in line with the above argument, phase shift will tend to increase. Once the shift reaches 180° we have effectively inverted our feedback signal – what was negative feedback has become positive feedback. Returning to the closed-loop gain equation from above: $A_C = A_O / (1 + \beta A_O)$. If the value of the term $(1 + \beta A_O)$ approaches zero then the value of A_C will tend towards infinity. That is infinite closed-loop gain – this results in instability, specifically the circuit oscillates. The condition for which $(1 + \beta A_O) = 0$ is $\beta A_O = -1$. This condition for instability specifically concerns the *loop gain*, not the closed-loop or open-loop gains.

Phase margin and gain margin

Looking at this in more detail, since A and β are phasor quantities (they have magnitude and phase shift), we get oscillation when the magnitude of βA (loop gain) is at least one (written $|\beta A| \geq 1$) and the phase shift due to βA_O is ±180°. Generally, the gain of an amplifier will decrease, and the phase shift will increase, as frequency increases. The question is – will the above conditions for instability occur as frequency increases? We can measure how close a circuit is to being unstable using the concept of gain margin and phase margin.

As the loop gain magnitude approaches 1 the phase shift must be less than 180°. The difference between the phase shift at this point and 180° is the phase margin. Second, as the phase shift around the loop approaches ±180° the magnitude of the gain must be less than 1 to prevent oscillation. This difference between the loop gain when its phase shift reaches 180° and 1 (which is 0dB) is the gain margin (usually expressed in dB).

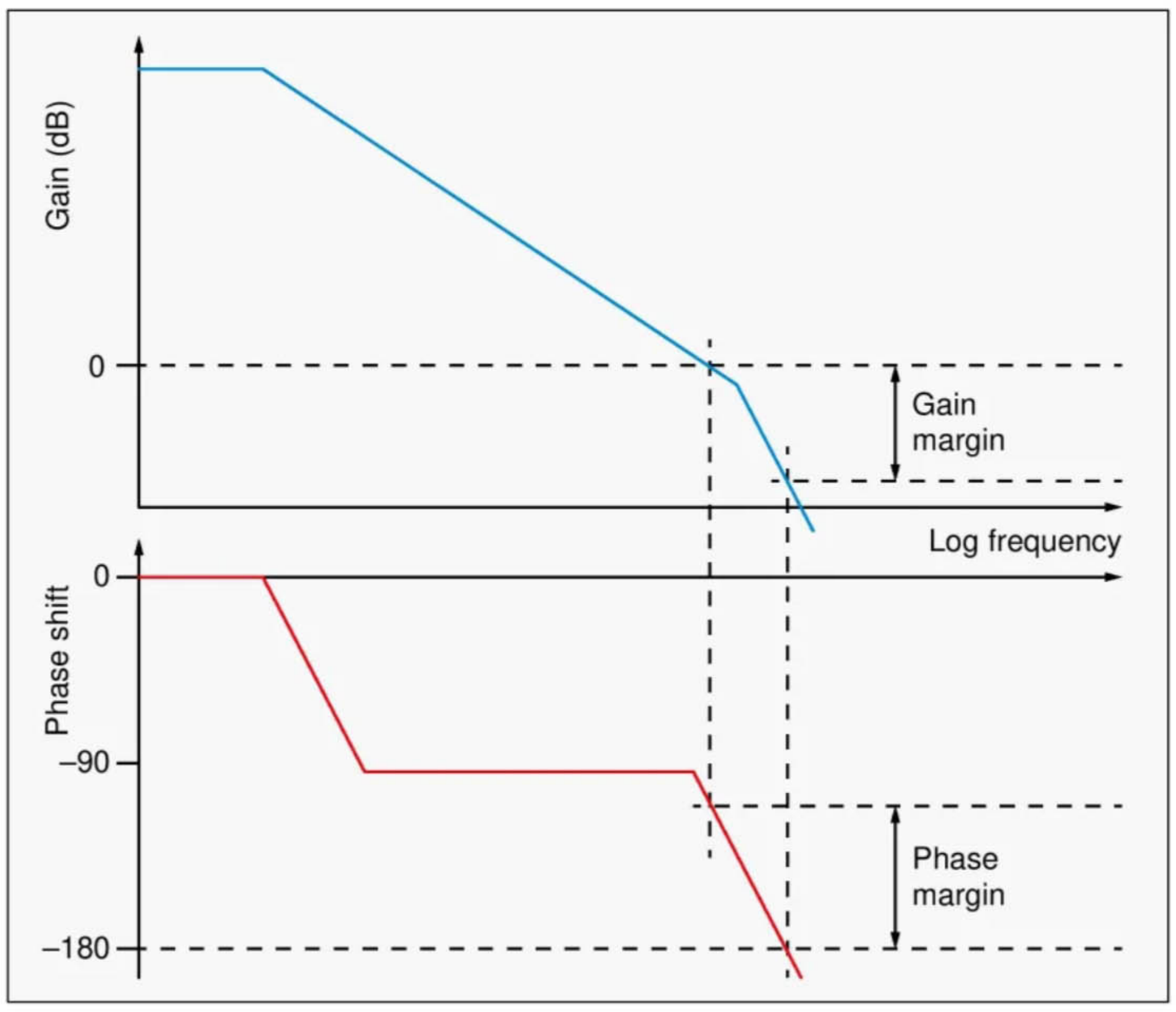
Fig.5 shows a frequency response plot for an amplifier loop gain with the gain and phase margins indicated. The gain margin and phase margin are a pair of values for a feedback amplifier which indicate its stability. These values are fixed for a given circuit and do not change with frequency (unlike phase shift and gain). If we can obtain a plot of loop gain and phase shift against frequency then it can be used to assess circuit stability. This is what LTspice's new frequency response analysis provides.

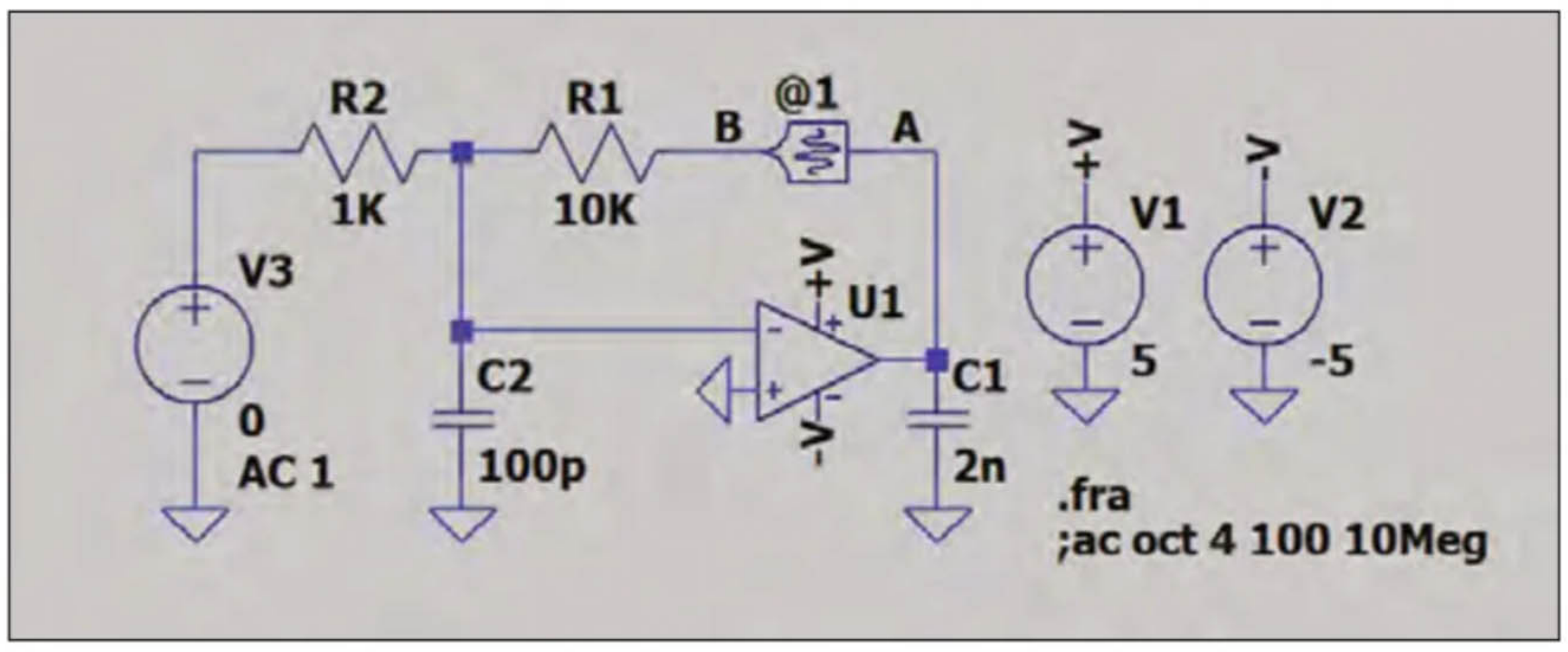
LTspice FRA example

Fig.6 shows an LTspice schematic of an op amp inverting amplifier configured for use with the new frequency response analysis (`.fra` directive). We will show a quick

Introduction to LTspice

Want to learn the basics of LTspice? Ian Bell wrote an excellent series of *Circuit Surgery* articles to get you up and running, see *PE* October 2018 to January 2019, and July/August 2020. All issues are available in print and PDF from the *PE* website:
https://bit.ly/pe-backissues





```
.fra
;ac oct 4 100 10Meg
```

Fig.5. (left) Example variation of gain and phase shift around a feedback loop (loop gain) with signal frequency, illustrating gain margin and phase margin.
Fig.6. (above) Example circuit for LTspice frequency response analysis.

example here and discuss LTspice frequency response analysis in more detail next month. The schematic in Fig.6 is based on an example provided by LTspice in the download. The circuit has an input voltage source added to provide a source for a standard AC analysis (`.ac` directive) to show closed-loop gain for comparison.

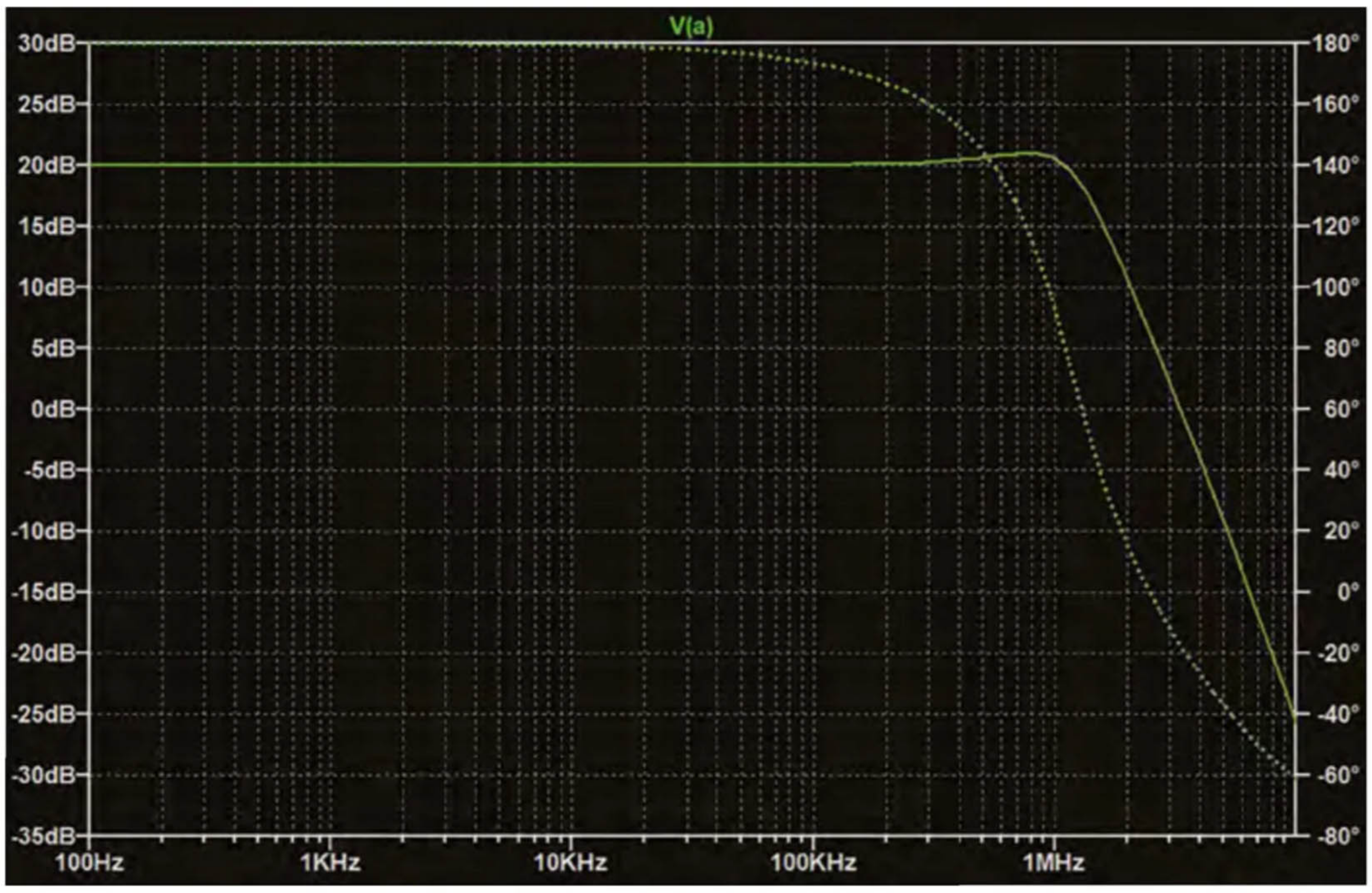
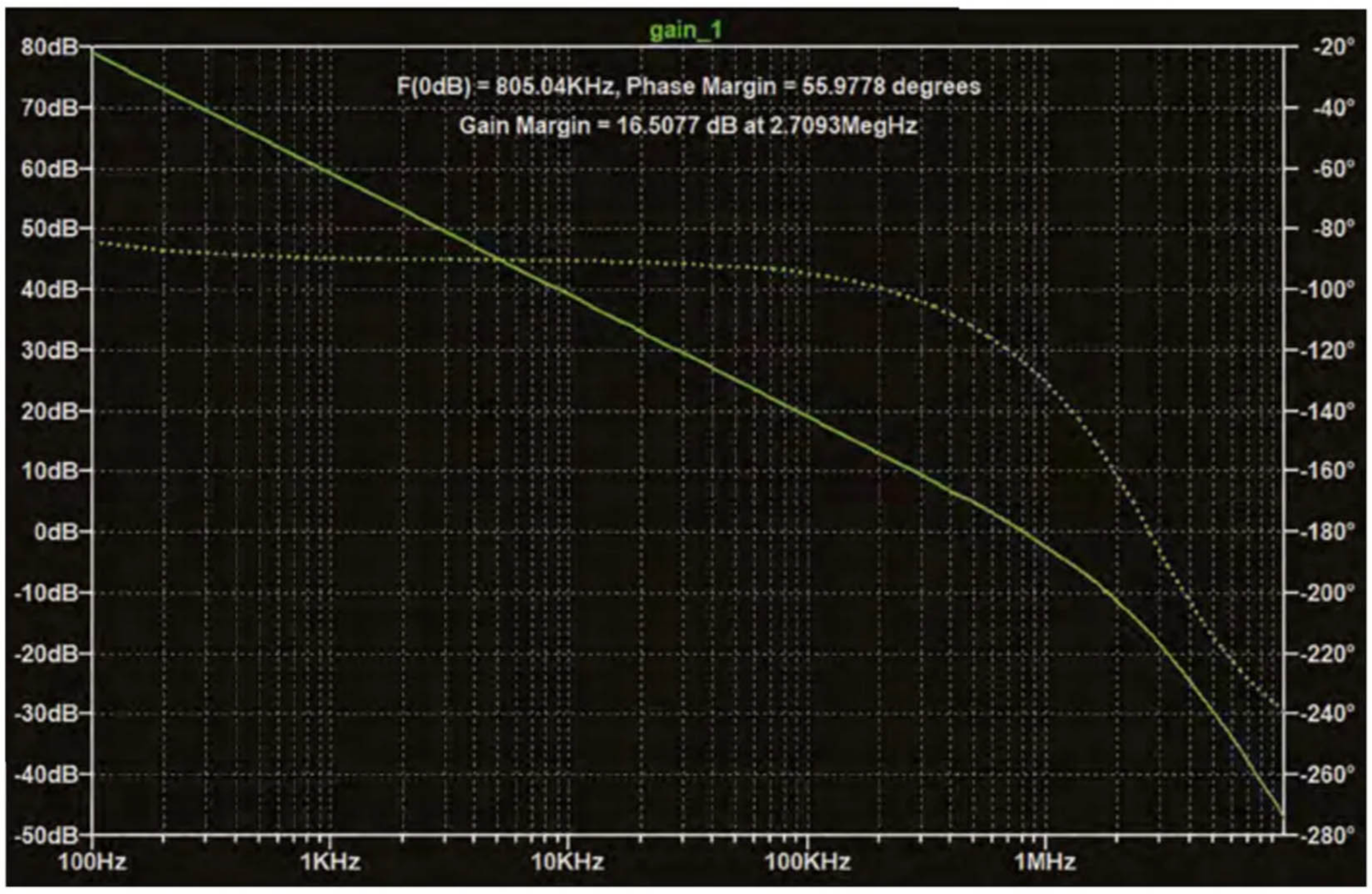


Fig.7. AC analysis results for the circuit in Fig.6 – this shows variation of closed-loop gain magnitude (solid) and phase (dotted) with frequency.



```
F(0dB) = 805.04KHz, Phase Margin = 55.9778 degrees
Gain Margin = 16.5077 dB at 2.7093MegHz
```

Fig.8. FRA results for the circuit in Fig.6 – this shows variation of loop gain magnitude (solid) and phase (dotted) with frequency.

To switch between the FRA and AC analysis swap the text on the schematic between comments and SPICE directives.

Frequency response analysis requires the addition of an FRA component to the schematic at a suitable point in the feedback loop, in series with the loop. In Fig.6 it is inserted between the op amp output and feedback resistors (between nodes `A` and `B`). The FRA component has initial letter @ in the same way that resistor names start with an 'R', capacitors with a 'C' etc. In order to run a frequency response analysis the `.fra` directive is used, as seen on the schematic. The operation of the frequency response analysis can be configured by right-clicking the FRA component. This example used the settings provided in the download example.

Before looking at the FRA results, Fig.7 shows a standard LTspice AC analysis for the circuit output at node `A`. The FRA component was disabled for this analysis. AC analysis requires an input source with an AC amplitude defined, which is `V3` in Fig.6. `V3` is a 0V DC source so it has no effect on the circuit other than for AC analysis. The results in Fig.7 show the variation of *closed-loop gain* with frequency.

The FRA results are shown in Fig.8 – this shows the variation of *loop gain* with frequency and can be used for stability analysis. LTspice prints the gain and phase margin values on the response plot. The results look similar – they are both frequency responses, but they are calculated in very different ways. The AC analysis used a linearised model of the circuit and requires a source with AC configured, whereas the FRA used transient simulation with waveforms at various frequencies and requires an FRA component – more on this next month.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website:
https://bit.ly/pe-downloads

Max's Cool Beans

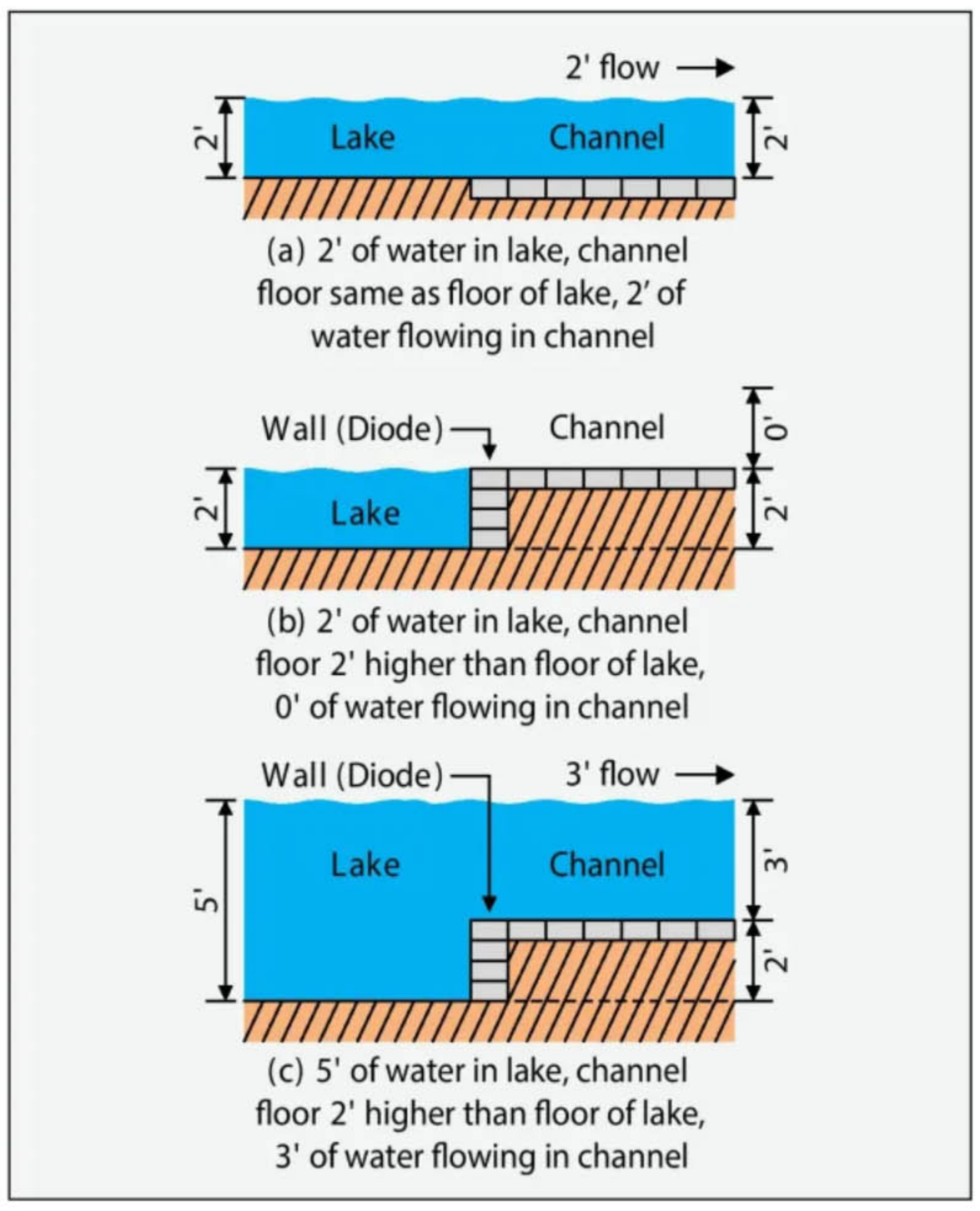
By Max the Magnificent

Arduino Bootcamp – Part 15

I fear we need to commence this column with a mini *mea culpa*. A couple of columns ago (*PE*, January 2024), I presented what I considered to be a rather cunning water-based analogy for the forward-voltage drop associated with diodes in general and light-emitting diodes (LEDs) in particular. Unfortunately, as I was to discover, that analogy wasn't cunning enough.

I've just received an email from a reader we will call Steve (because that's his name). This email was short, sharp and to the point, reading as follows:

Your recent column shows a lamentable lack of hydrodynamic intuition, leading you to be proud of an analogy that didn't really seem to explain what you were trying to achieve. Maintaining the analogy between voltage and depth of water, a better metaphor for the diode voltage drop might have been a channel whose floor was higher than the floor of the lake feeding it. The channel would remain empty until the water level (voltage) is high enough. So, the diode voltage drop is represented by the difference in floor levels. Once the water level reaches the bottom of the channel, it (current) starts to flow, and the depth of the channel will be the depth of the lake minus the floor level difference. To me this seems a rather more intuitive explanation than your somewhat tortured diagram. Happy New Year!



(a) 2' of water in lake, channel floor same as floor of lake, 2' of water flowing in channel

(b) 2' of water in lake, channel floor 2' higher than floor of lake, 0' of water flowing in channel

(c) 5' of water in lake, channel floor 2' higher than floor of lake, 3' of water flowing in channel

Fig.1. Graphical depiction of a diode's forward-voltage drop.

What can I say? I can only blame my lamentable lack of hydrodynamic intuition on my dear old mother, who firmly believed that torrid tales of a hydrodynamic nature were not well-suited for the supper table. Be this as it may, it must be admitted that surly Steve is correct, and his analogy is far better than mine. I hang my head in shame, and I shall chastise myself soundly as soon as I've finished writing this column. For your future reference, an updated version of this analogy is shown in Fig.1.

As before, we use a lake to represent our power source. This lake feeds a channel, which represents a wire. The height of the water in the lake is equivalent to voltage and any flowing water is equivalent to current. Fig.1a depicts a lake with 2 feet of water (equivalent to 2V in our electrical circuit) and an unobstructed channel through which the water from the lake is free to flow.

By comparison, in Fig.1b we raise the channel such that its floor is 2-feet higher than the floor of the lake. The wall where the channel meets the lake represents our diode, whose forward-voltage drop we are assuming to be 2V. In this case, assuming the water in the lake is still only 2-feet deep, no water will flow through the channel.

Finally, in Fig.1c, we increase the depth of the water in the lake to 5 feet. Since the floor of the channel is 2-feet higher than the floor of the lake, the result will be 3 feet of water flowing through the channel. (For those of you outside the US, where I live, 2 feet is often abbreviated to 2', and 3 feet is (very) roughly a metre.)

A beatitude of breadboards

Thus far, we've performed all our experiments on a single full-sized breadboard. However, we now need to spread our wings a little by adding a second board. In my previous column (*PE*, February 2024), I made mention of the fact that my friend Joe Farr ran across a source of extremely low-cost, high-quality breadboards. Joe immediately snapped up 25 of these little rascals. I hope you also took advantage of this splendid offer.

There's a lot more to the humble breadboard than first meets the eye – the folks at SparkFun have a great tutorial on the anatomy of these little scamps: **https://bit.ly/41LsGkX**

If you look closely at the underside of your breadboard, for example, you'll see that what you initially assumed to be some sort of boring backing material is, in fact, covered in adhesive on both sides. One side is stuck to the bottom of the breadboard. You can peel the protective covering off the other side, and then use the adhesive to attach your board to a larger worksurface.

So, if we wish to use two boards, we could simply stick both to a common platform, which could be anything from a thick piece of card to the wall of your family room. But wait, there's more. If you look closely, you will see that there are dovetailed nubbins projecting from one side of the board with corresponding slots on the other side (Fig.2). These features allow you to connect multiple breadboards together without having to attach them to a larger base. Some boards also have nubbins and slots at their ends. Also, note that different manufacturers may have different sized/shaped nubbins and slots in different places, which can make things awkward should you wish to mix-and-match offerings from multiple vendors.

And there's still more. Return to Fig.2 and observe the narrow grooves delimiting the terminal strips in the center of the board from the power rails at the top and bottom of the board. These

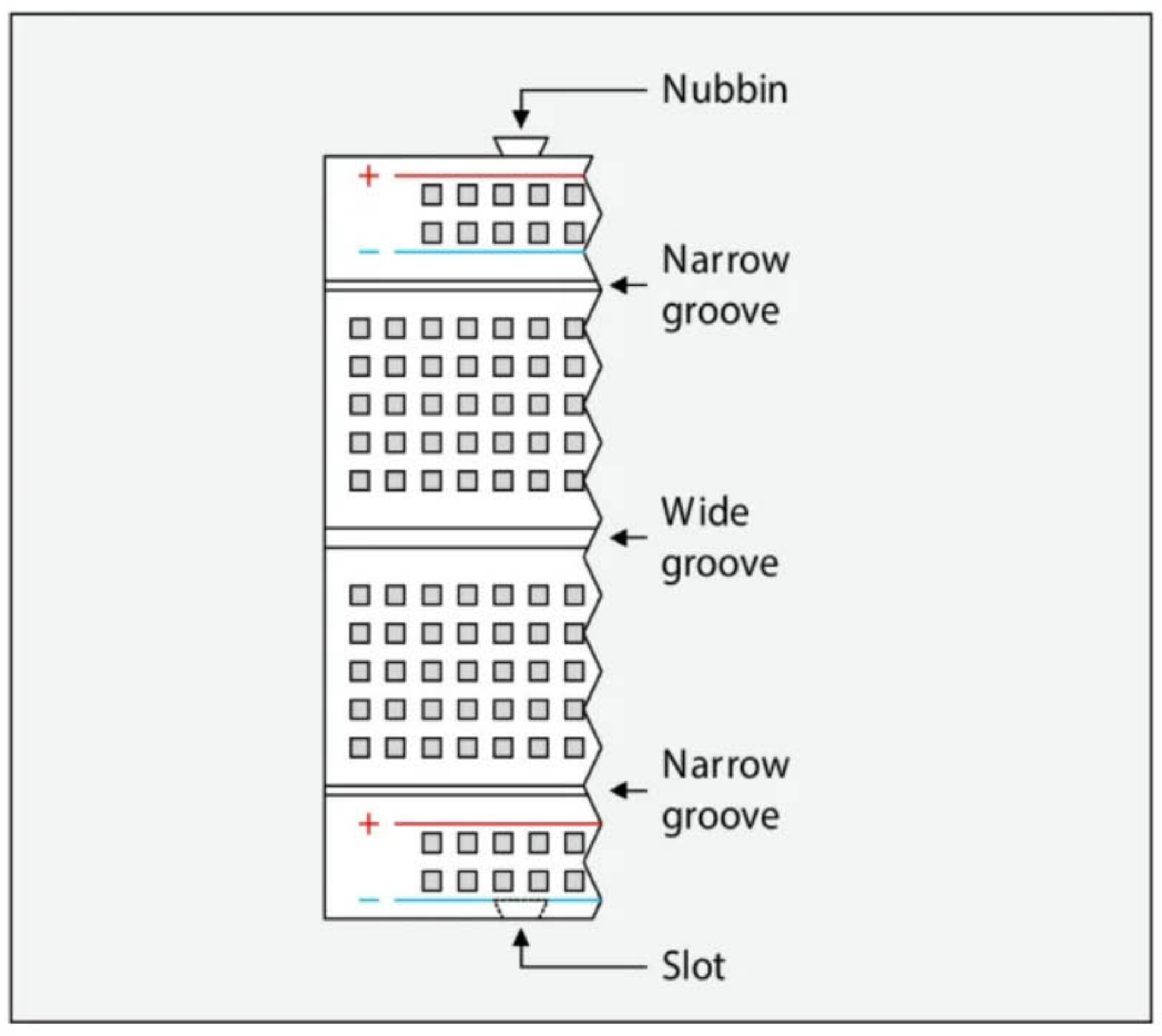


Fig.2. Meet the nubbins.

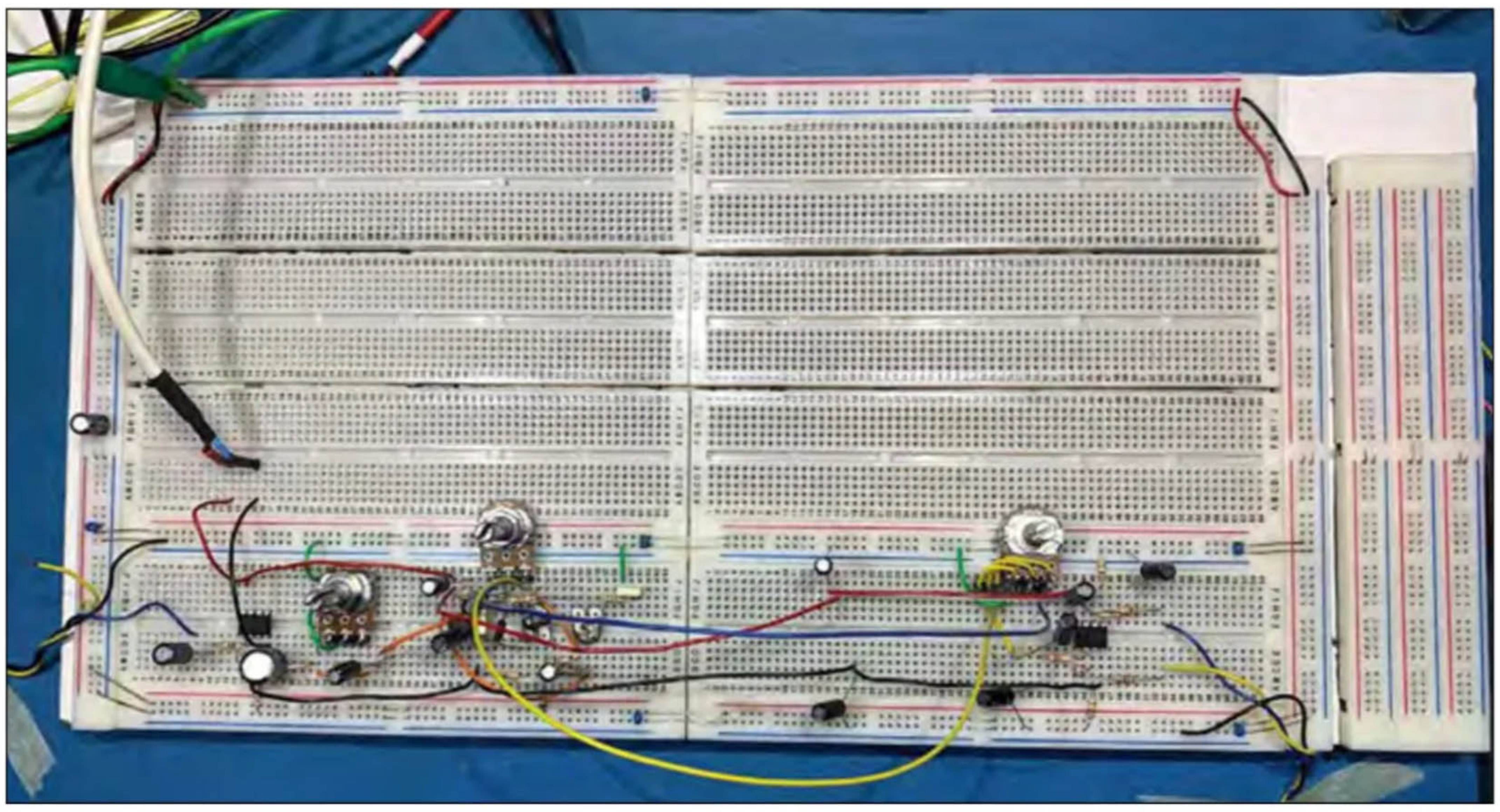


Fig.3. Example of a multi-breadboard assembly.

grooves aren't simply aesthetic artifacts. The power rails are attached to the main board by means of their own nubbins and slots. If you flip the board over, you can use a hobby knife (eg, an X-Acto knife) to cut through the double-sided adhesive backing along lines corresponding to the narrow grooves, after which you can separate the power rails from the main board. Joe sent me a photo of a prototype project he recently started (Fig.3). Note how some of the power rails have been removed from the breadboards in the middle and relocated to the left- and right-hand sides of the breadboard array. Also, you can see in Fig.3 how all the boards are attached to a large piece of white card.

You're welcome

We are about to embark on the creation of a compendium of chronometers that present time (hours and minutes) using one, two, and four 7-segment displays. As part of this, we are going to be introducing several interesting integrated circuits (ICs).

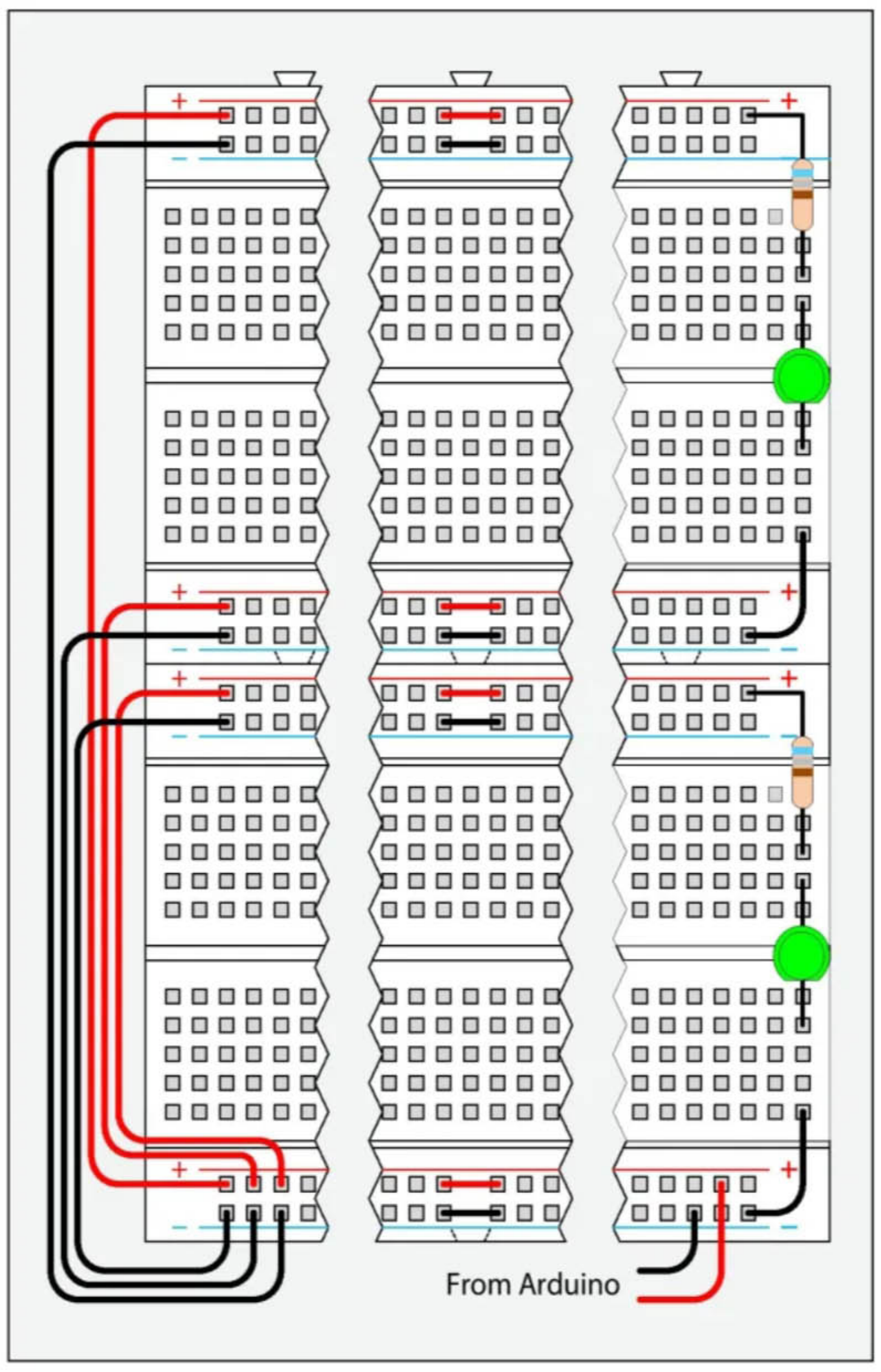


Fig.4. Preparing our dual board combo.

Since I have piles of breadboards lying around (they seem to accumulate over the years), I was tempted to move to using three boards – one for the 7-segment displays, one for the integrated circuits, and one to act as a sort of patch panel, thereby allowing me to re-route connections quickly and easily between the 7-segment displays and the ICs.

But then it struck me that if you are buying new breadboards individually, you would probably prefer to spend less money and use fewer boards. So, after mulling this over, I determined that we could muddle and meander our way through using only two breadboards. You're welcome.

Preparing our dual-board combo

Setting up our dual-board combo is really just an extension to the way in which we inaugurated our original breadboard at the start of this series (*PE*, January 2023). We commence by connecting two breadboards together using their nubbins and slots (Fig.4). We use two flying leads to bring power (+5V, red) and ground (0V, black) from our Arduino into the bottom right-hand corner of the combo.

The reason for adding the little red and black wires linking the power and ground rails in the middle of the boards is that some breadboards have split power rails, which may or may not be indicated by breaks in their red and blue graphical lines. This is discussed in my *Arduinos and Solderless Breadboards* blog at: **https://bit.ly/3NZ70uF**

Your boards may have continuous rails, in which case you don't need to add these wires, but it's good practice to do so to prevent being caught out in the future (it's said that you learn from your mistakes, but – in my experience – it's better to learn from other people's mistakes, so – in this case – you can learn from my mistakes; once again, you're welcome).

On the left-hand side of the boards, we use jumper wires to carry power and ground from the lower set of rails to the other three sets. Why didn't I decide to daisy chain these from one set of rails to the next? There are two reasons. First, I wish to minimise voltage-drop effects, and every additional connection adds a little more resistance. Second, this setup will be a tad easier to debug if any of my power or ground wires fail.

Finally, we return to the right-hand side of the boards. For each board we add a green LED with an associated current-limiting resistor. The green LEDs I'm using have a forward-voltage drop of 3V and can support a maximum forward current of 20mA. This means that if we wished these to shine as brightly as possible, then we would use 100Ω resistors (the way we calculate this value was discussed in *PE*, January 2023). In this case, however, I don't want these LEDs to be too bright because they hurt my eyes, plus they last longer when we use less than the maximum allowable current, so I've used 680Ω (blue, grey, brown) for my current-limiting resistors. This limits the current to around 3mA, but the LEDs are still more than bright enough to serve their purpose.

The reason for including these LEDs in our setup is that – every time we apply power to the boards – they provide confirmation that everything is connected as it should be and that we are getting power and ground to all the right places. Actually, '*all* the right places' is not strictly true. We could do better. Can you see how? The answer is presented at the end of this column.

The thing is, it's a lot easier to weed out fundamental mistakes at this stage before we start adding more sophisticated components. And, more importantly, verifying that our power and ground connections are correct can prevent us from damaging other components when we add them to our breadboards.

I just powered up my Arduino, and little tears of joy are rolling down my cheeks because both my green LEDs are glowing gloriously.

If you wish, you can download an image of the entire setup described above, including the connections to our Arduino Uno (file **CB-Mar24-01.pdf**). As usual, all the files mentioned in this column are available from the March 2024 page of the *PE* website: **https://bit.ly/pe-downloads**

Adding a 7-segment display

In the fullness of time, we will be using four 7-segment displays that we will call D0, D1, D2 and D3 to our upper breadboard. For the moment, we will simply add D0 on the left-hand side of the board as illustrated in Fig.5, which

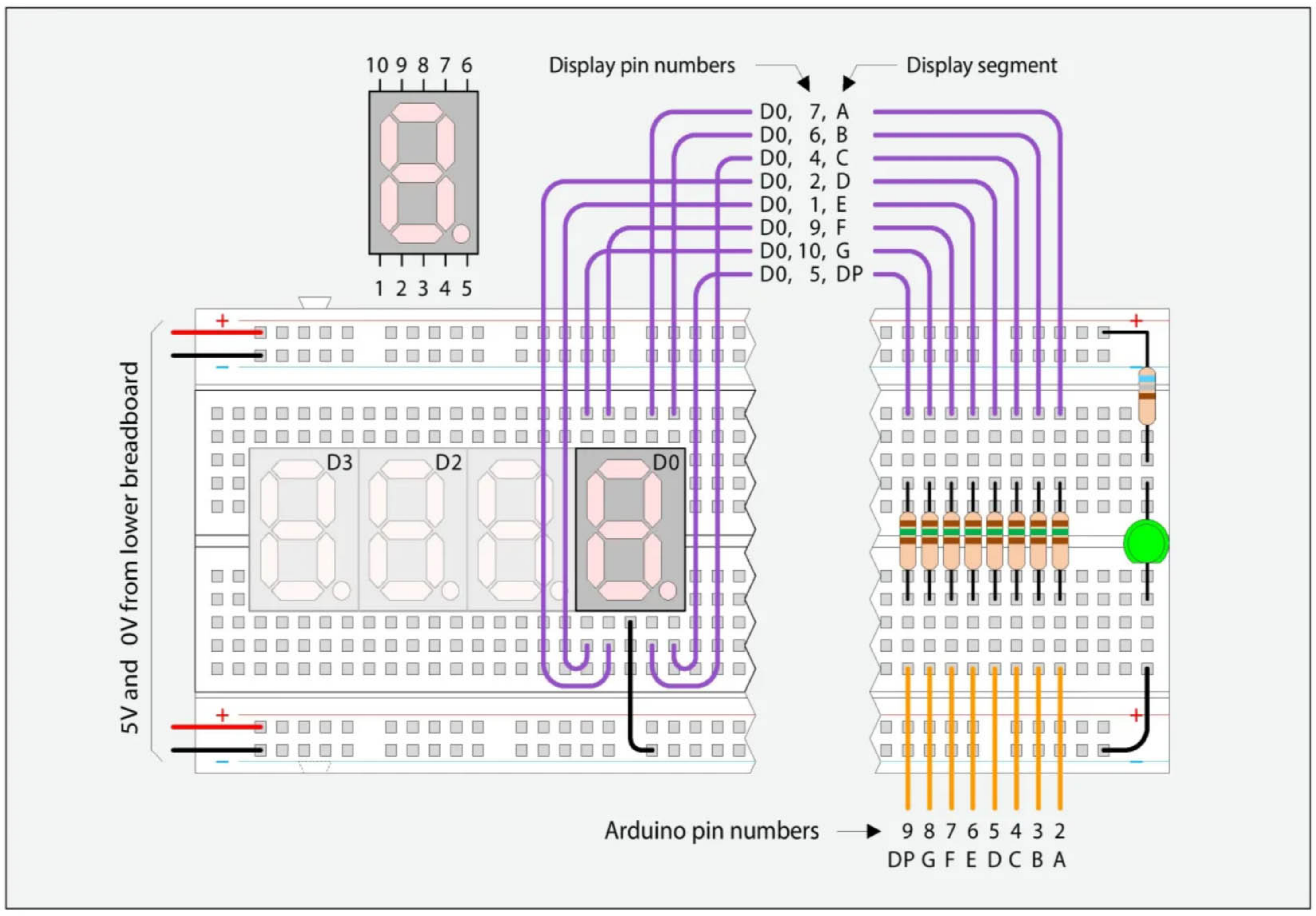


Fig.5. Adding our first 7-segment display.

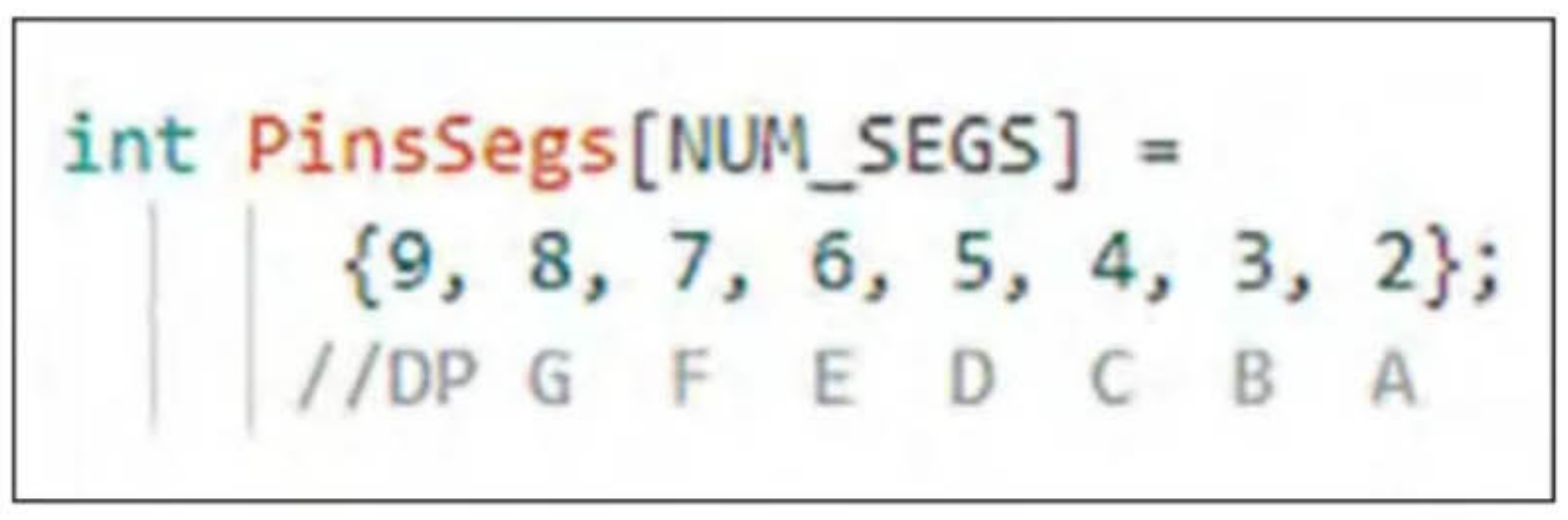
also indicates where the other displays are to be added in the future.

Before we do anything else, let's connect a black wire between pin 3 of our D0 display and the nearest 0V power rail (it's easy to forget to do this later in the excitement of the moment when we try to wrap our brains around the rest of the wiring).

Next, let's add eight current-limiting resistors on the right-hand side of the board. As we've previously discussed, the red LEDs in the displays we're using have a forward-voltage drop of 2V and a maximum forward current of 20mA. For the moment, we're going to use the same 150Ω (brown, green, brown) resistor values we've used before because this will give us our 20mA. In turn, this will result in maximum brightness, which will become important when we start multiplexing between multiple displays in a future column.

Now let's add the eight purple wires (or any colour of your choosing) between the 7-segment display and the tops of the current-limiting resistors. Finally, add the eight orange wires between the bottoms of the resistors and the Arduino. Observe that we are using a different Arduino-to-Display pin mapping to what we've used before. This makes the wiring easier on the right-hand-side of the boards, which will make our lives straightforward as we start to add more displays (well, that's the plan, anyway).

Once again, you can download an image of our latest and greatest dual breadboard setup, including the connections to our Arduino Uno – see file **CB-Mar24-02.pdf**.



```
int PinsSegs[NUM_SEGS] =
    {9, 8, 7, 6, 5, 4, 3, 2};
    //DP G  F  E  D  C  B  A
```

Listing 3a. New pin assignments.

Does everything work?

Do you recall those distant halcyon days (as depicted in *PE*, April 2023 for the delectation and edification of future generations) when we created a program to repeatedly count from 0 to 9 and to display these values on our 7-segment display?

Well, I just forked (copied) that program and gave it a tiny tweak. The modified file is available for you to download: **CB-Mar24-03.txt.**

As illustrated in Listing 3a, all we needed to do to get this program to work on our new dual-board combo was to change the Arduino pin numbers associated with the segments on the 7-segment display. (Remember that, following some confusion in earlier columns, we're now using a scheme in which the listing number [Listing 3 in this example] corresponds to the associated program file [**CB-Mar24-03.txt** in this example], after which we use 'a', 'b', 'c', … suffixes as appropriate.)

Not surprisingly, these new pin assignments reflect those shown in Fig.5 (we'd be in a bit of a pickle if they didn't). I just powered-up my Arduino. I wish you could see my 7-segment display merrily counting away.

Handy-dandy reference sheets

Before we proceed, every now and then it's necessary to refer to some reference values. When we perform a theoretical calculation, we may end up with a desired current-limiting resistor value of 213.268Ω, for example.

The problem here is that no one makes this value of resistor. If we look this up, we find the closest values in the series we are using are 200Ω and 220Ω. In the case of a current-limiting application, we would go for the higher value, which will result in a (safer) lower current.

Tracking these available values down can be a pain, so Joe has created a set of handy-dandy reference sheets for himself. He keeps laminated copies on his workbench. Also, he's kindly agreed to share them with the rest of us: **CB-Mar24-04.pdf**.

And, while we are on this topic, if you've ever wondered as to how the various resistor values came to be decided on, you should check out the links to Parts 10 and 11 in my *What Are Voltage, Current, and Resistance?* Blog: **https://bit.ly/3NV4Flw**

Tick tock, tick, tock…

If we wish to create a clock, then you probably won't be surprised to hear that one of the things we are going to need to know is the time to be displayed.

We discussed resonators and oscillators in an earlier *Techno Talk* column (*PE*, January 2024). The Arduino has a quartz oscillator that acts as its system clock, and it can use this oscillator to keep track of time via its internal timers. Unfortunately, the Arduino's oscillator is cheap-and-cheerful and prone to drifting slightly. This isn't a problem in the usual scheme of things, but we certainly don't want our terrific timepiece to lose or gain a few seconds each day. Also, we would be obliged to reset our clock and re-enter the time every time we powered the Arduino down and up again, which would be a pain.

To get around these problems, we use an integrated circuit called a real-time clock (RTC) whose sole purpose in life is to mark the passage of time as accurately as possible. Furthermore, we use an RTC equipped with a backup battery, which means it can continue to keep track of time in the event of a power failure (in the case of a real clock) or the powering down of our Arduino (in the case of our prototype projects).

The RTC I opted to use is the DS3231 Precision RTC Breakout Board (BOB) from Adafruit – see: **https://bit.ly/3TRvjjk**

As illustrated in Fig.6, this bodacious beauty is based on the DS3231 chip, whch comes from Analog Devices, see: **https://bit.ly/48IJxam**

Readers in the UK can purchase a DS3231 BOB from Amazon at: **https://bit.ly/3S9OjHl**

To be honest, there are a lot of cheaper RTCs available, such as the DS1307 chip from Analog Devices or the PCF8523 and PCF8563 chips from NXP Semiconductors, and Adafruit has BOBs for them all. You can use whichever device you want (see also the discussions on RTClib below),

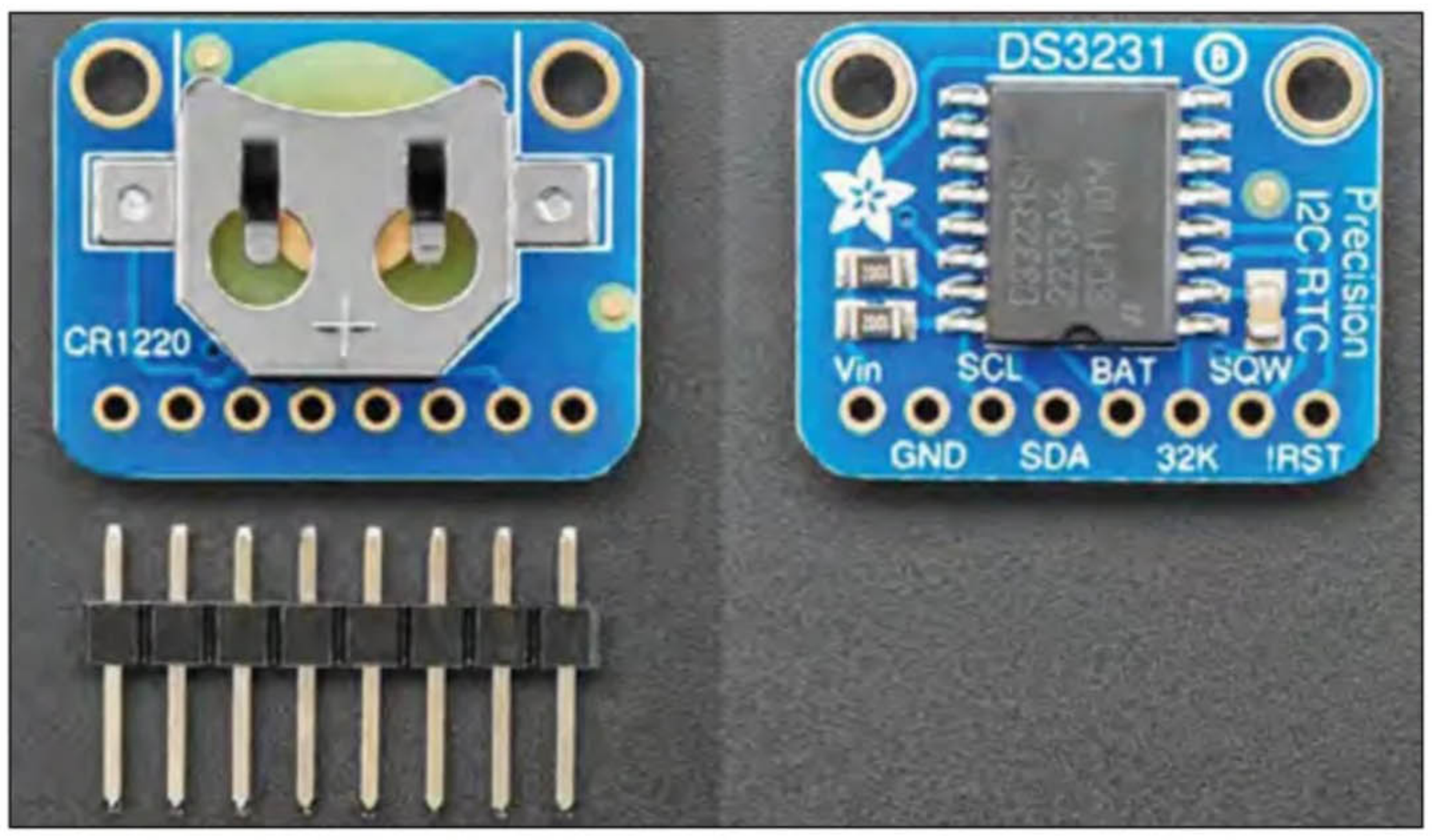


Fig.6. The DS3231 precision RTC BOB (real-time clock breakout board) (Source: Adafruit).

but the DS3231 is the most accurate you can get in this price range and it's the one I use for all my projects.

One small point is that the 8-pin header strip comes separately, so you'll have to solder this yourself. You want the long pins pointing down to push into your breadboard, and you want the IC side of the board facing upwards. If you aren't used to soldering, now would be a good time to start learning. A great resource is *The Basic Soldering Guide Handbook*, which was written by *PE's* very own Alan Winstanley and is available on Amazon: **https://bit.ly/3H7LUaO**

You'll also need a CR1220 lithium coin cell battery, which is sold separately. When you are inserting this little rascal, make sure the large metal side of the battery (with the plus '+' sign) mates with the outward-facing side of the battery clip (also with a '+' sign, as seen in Fig.6).

Incorporating the DS3231 RTC

Once we've added the header pins and backup battery to your RTC, we can incorporate it into the left-hand side of our lower breadboard, as illustrated in Fig.7. Yes, of course you can download an image of our latest and greatest dual breadboard setup, including the 7-segment display, the RTC, and any ancillary components and wiring, along with all the connections to our Arduino Uno (file **CB-Mar24-05.pdf**).

One of the reasons I like Adafruit's DS3231 RTC is that they provide a treasure-trove of information in their online tutorial: **https://bit.ly/3RQQMG9**

Consider the input/output (I/O) pins shown in Fig.6 and Fig.7. First up are Vin and GND, which we will connect to the power and ground rails on the breadboard as illustrated in Fig.7 (this RTC can be powered from 2.3V to 5.5V). It's best to connect things without power being applied to the board but – if you like to live dangerously – then always connect the ground wire first.

The next step is to connect the DS3231 to the Arduino using the green and blue wires shown in Fig.7. The DS3231 and the Arduino communicate via a 2-wire I^2C (Inter-Integrated Circuit) bus. This bus is bidirectional, which means we can use the Arduino to tell the RTC what the current time is (we only do this once or if we need to change things later for some reason or other), after which the Arduino reverts to asking the RTC for the current time.

The two wires in the I^2C bus are called SCL (the clock) and SDA (the data). These signals require 10kΩ pull-up resistors, but we don't need to worry about that because these resistors are already included on the DS3231 breakout board.

Unfortunately, there aren't any SCL and SDA annotations on the Arduino board. A pinout diagram is available on the Arduino website – see: **https://bit.ly/48pLOrd** – but I prefer the more-detailed version created by Alberto Piganti at: **https://bit.ly/41LTNMJ**

One important point to note is that the Arduino's SCL and SDA pins shown in Fig.7 are also connected to the Arduino's A5 and A4 analogue input pins, respectively (this is reflected in Alberto's version of the pinout diagram). This means we cannot use the A4 and A5 pins as analogue inputs if we are already using them to perform I^2C communications.

The great thing about I^2C is that you can have multiple devices like sensors and actuators all controlled using the same two pins on the Arduino. This means that each device requires its own address for everyone to know who is talking to whom. The DS3231 breakout board has a default address of 0x68 in hexadecimal (104 in decimal), and this address cannot be changed.

We aren't planning on using the DS3231's other pins at the current time, but it's worth noting what they do in case we decide to use them later. The BAT pin is connected to the positive side of the coin cell battery. The 32K pin provides a 32kHz oscillator output, while the SQW pin provides an optional square wave, which can be used as an interrupt to the Arduino (both these

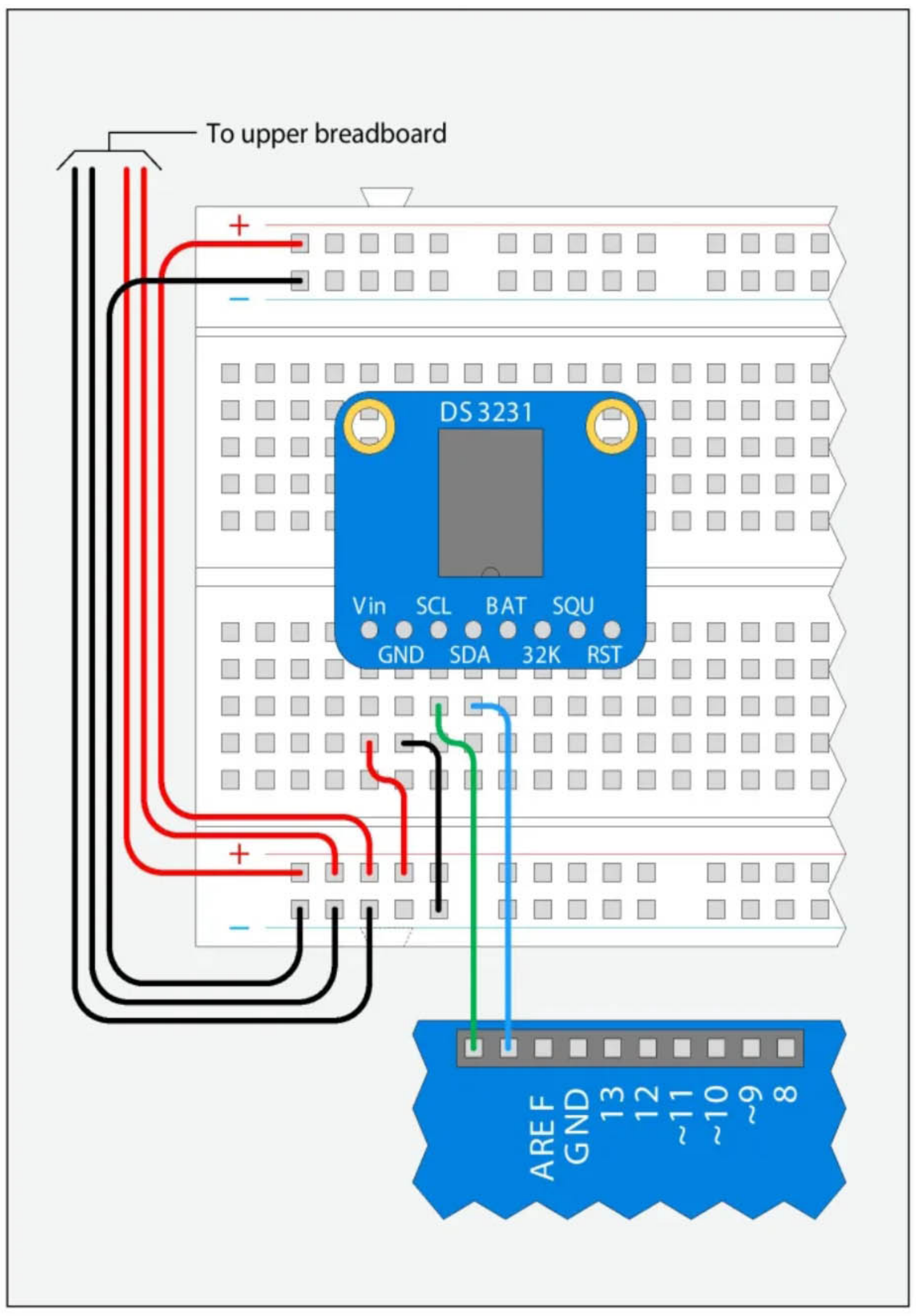
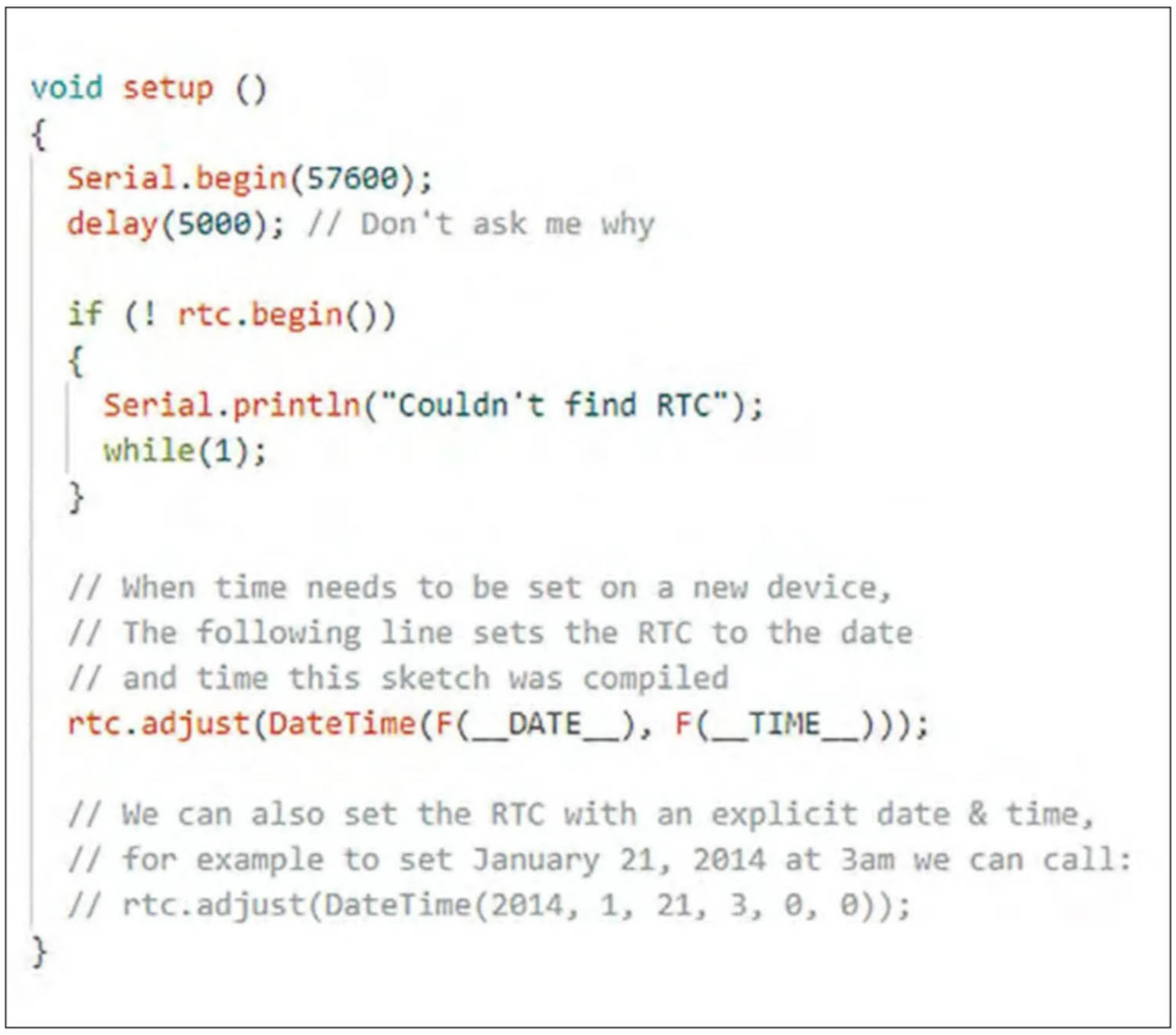


Fig.7. Adding the RTC.



```
void setup ()
{
  Serial.begin(57600);
  delay(5000); // Don't ask me why

  if (! rtc.begin())
  {
    Serial.println("Couldn't find RTC");
    while(1);
  }

  // When time needs to be set on a new device,
  // The following line sets the RTC to the date
  // and time this sketch was compiled
  rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));

  // We can also set the RTC with an explicit date & time,
  // for example to set January 21, 2014 at 3am we can call:
  // rtc.adjust(DateTime(2014, 1, 21, 3, 0, 0));
}
```

Listing 6a. Initialising the RTC.

Online resources

For the purposes of this series, I'm going to assume that you are already familiar with fundamental concepts like voltage, current and resistance. If not, you might want to start by perusing and pondering a short series of articles I penned on these very topics – see: **https://bit.ly/3EguiJh**

Similarly, I'll assume you are no stranger to solderless breadboards. Having said this, even if you've used these little scamps before, there are some aspects to them that can trap the unwary, so may I suggest you feast your orbs on a column I wrote just for you – see: **https://bit.ly/3NZ70uF**

Last, but not least, you will find a treasure trove of resources at the **Arduino.cc** website, including example programs and reference documentation.

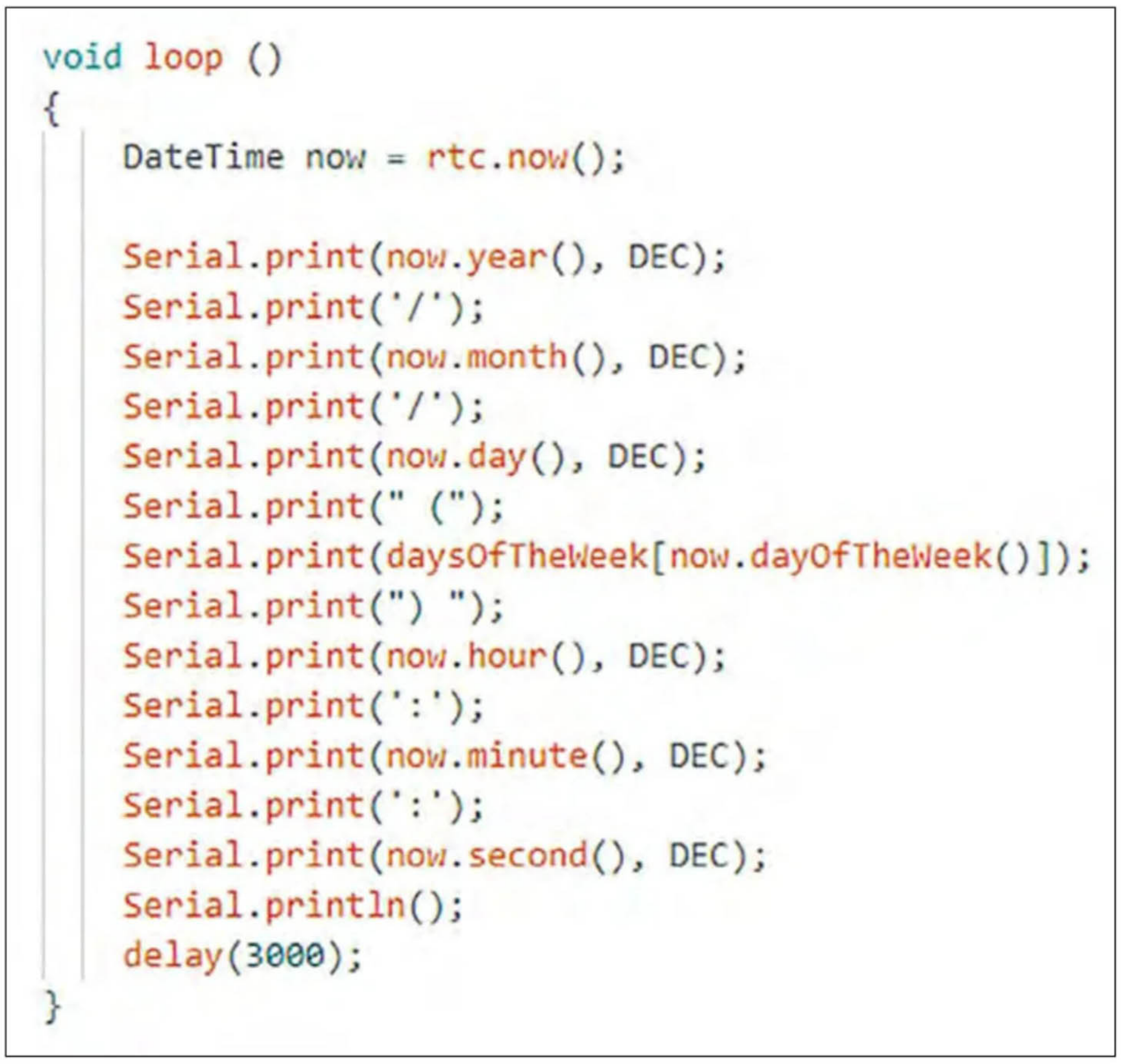
pins require pullups if we wish to connect them to the Arduino). Last, but not least, we have the RST ('reset') pin. This is a bit different to other reset signals you may have seen because it isn't used to reset the RTC; instead, the RTC can use it to reset (or inform) other devices whenever main power is lost.

RTClib and first RTC tests

In order to use our RTC, we are going to need a special library. A few years ago, a guy called Jean-Claude Wippler of JeeLabs fame created an awesome RTC library called RTClib. The folks at Adafruit forked (and subsequently modified) a form of this library, and that's the one we're going to use. In addition to our DS3231 RTC, Adafruit's RTCLib also supports the DS1307, PCF8523 and PCF8563 RTCs we mentioned earlier.

Instructions on how to download and install Adafruit's version of RTClib can be found in the aforementioned Adafruit tutorial. Remember to exit and restart the Arduino IDE after you've installed the library.

As you will see in their tutorial, the folks at Adafruit provide some great example programs for the RTC. Since a lot of their stuff isn't of interest to me, I've forked their main example and used it as the basis for a couple of my own.



```
void loop ()
{
    DateTime now = rtc.now();

    Serial.print(now.year(), DEC);
    Serial.print('/');
    Serial.print(now.month(), DEC);
    Serial.print('/');
    Serial.print(now.day(), DEC);
    Serial.print(" (");
    Serial.print(daysOfTheWeek[now.dayOfTheWeek()]);
    Serial.print(") ");
    Serial.print(now.hour(), DEC);
    Serial.print(':');
    Serial.print(now.minute(), DEC);
    Serial.print(':');
    Serial.print(now.second(), DEC);
    Serial.println();
    delay(3000);
}
```

Listing 6b. Retrieving values from the RTC.

Let's download, peruse and ponder my first program (file **CB-Mar24-06.txt**). We start by including the RTClib library we just installed. Next, we instantiate our real-time clock and we call it `rtc` (so, no surprises there). We also declare a 2-dimensional array of characters called `daysOfTheWeek[][]` to which we assign the names of the days of the week ('Sunday,' 'Monday,' 'Tuesday,' … and so on).

Now let's consider the `setup()` function shown in Listing 6a. Observe that when the serial communications are initialised on Line 9, it's with a baud (communication) rate of 57600. For the purposes of these discussions, we can think of 'baud rate' as meaning 'bits-per-second,' but don't say this to a professional engineer because they will bore you to death with an explanation of what baud rate really is. In our earlier experiments, we've always used the default baud rate of 9600. So, now you have a choice, you can change this value to 9600 in the code, or you can do what I did, which is to click on the Serial Monitor icon in the Arduino IDE and change *its* rate to 57600. The main thing is that baud rates in the code and the Serial Monitor match.

Line 12 calls the `rtc.begin()` function to initialise the RTC and set the ball rolling. Like all functions of this type, this returns a value of 0 (`false`) or 1 (`true`) to reflect whether or not the RTC is online and responding. If we were to use `rtc.begin()` on its own, its return value would be discarded. In this case, however, we are using it as part of a test, which basically says 'If not rtc.begin()' or 'If rtc.begin doesn't return a true value' then…

The bottom line is that if the program cannot detect our RTC, it will print 'Couldn't find RTC' in the serial monitor window and then loop around twiddling its metaphorical thumbs. In fact, this just happened to me. 'Oh dear,' I said to myself (or words to that effect). I rechecked all my wiring and used my multimeter to ensure the RTC's connections to 5V and GND were good. Next, I had a quick Google while no one was looking to see if the interweb had any words of wisdom to offer. It did. It said, 'Check your solder connections' and 'Check your jumper wires.' My solder connections looked good, so I simply swapped out my blue and green jumper wires, and everything was fine (phew!).

Since we only recently added the battery to our RTC, we need to tell it what the time is. We do this using a call to the `rtc.adjust()` function on Line 21. Don't ask me how this works, but it sets the RTC to the date and time this program was compiled and loaded into our Arduino.

Observe the comments on Lines 23 through 25. These tell us how we can use the `rtc.adjust()` function to load the RTC with an explicit date and time. If we decide to add some pushbuttons to our clock in the future, we can use them in conjunction with this function to change the date and time (perhaps to set an alarm function or to reflect daylight saving time, for example).

Now let's consider the `loop()` function as illustrated in Listing 6b. One of the things RTClib does is declare a new data type called `DateTime`. In fact, this is a structure containing multiple members whose values we can access using full-stop/period '.' delimiters (we introduced enumerated types, structures, and type definitions in *PE*, December 2020). On Line 31, we declare a variable called `now` which is of type `DateTime` to which we assign the values returned from a call to the `rtc.now()` function.

In Lines 33 through 46 we use a series of calls to the `Serial.print()` function to access some of the fields in our now variable and print these values in the Serial Monitor. For example, the Serial Monitor on my host computer is currently showing the following:

Components from Part 1	
LEDs (assorted colours)	https://amzn.to/3E7VAQE
Resistors (assorted values)	https://amzn.to/3O4RvBt
Solderless breadboard	https://amzn.to/3O2L3e8
Multicore jumper wires (male-male)	https://amzn.to/3O4hnxk
Components from Part 2	
7-segment display(s)	https://amzn.to/3Afm8yu
Components from Part 5	
Momentary pushbutton switches	https://amzn.to/3Tk7Q87
Components from Part 6	
Passive piezoelectric buzzer	https://amzn.to/3KmxjcX
Components for Part 9	
SW-18010P vibration switch	https://bit.ly/46SfDA4
Components for Part 10	
Breadboard mounting trimpots	https://bit.ly/3QAuz04
Components for Part 12	
Light-Dependent Resistor	https://bit.ly/3S2430m
Components for Part 13	
BC337 NPN Transistor	https://bit.ly/40xAgyS
Components for Part 14	
HC-SR04 Ultrasonic Sensor	https://bit.ly/49AMBq4
Components for Part 15	
Real-Time Clock (RTC)	https://bit.ly/3S9OjHl

```
    :
2024/1/7 (Sunday) 16:48:55
2024/1/7 (Sunday) 16:48:58
2024/1/7 (Sunday) 16:49:1
2024/1/7 (Sunday) 16:49:4
2024/1/7 (Sunday) 16:49:7
2024/1/7 (Sunday) 16:49:10
    :
```

Now download my second program (file **CB-Mar24-07.txt**). You will see the `loop()` function is identical to our previous program. However, the `setup()` function has changed. All it does now is start the RTC; it no longer loads it with a new date and time.

Load and run this second program and observe the date and time values appear in the Serial Monitor. Now, power-down your Arduino, count to 10, power it back up again, open the serial monitor, and observe that the RTC remembered the time when power was removed from the system (tra la!).

And the answer is…

When we were discussing the setting up of our dual-board combo earlier in this column, I noted that we weren't truly verifying the fidelity of all our power and ground rails. The way our original green LEDs are located (Fig.4), we are only verifying the upper power rail and the lower ground rail on each board. This has never been a problem in the past for me personally because these are the rails I predominantly use. Now I come to think about it, however, it would be a good idea to add a pair of blue LEDs as illustrated in Fig.8.

Why blue? Why not? We could carry on using green LEDs but – if nothing else – the blue versions certainly make Fig.8 easier to understand. Also, the green and blue look pretty on the board. Furthermore, my blue LEDs have the same 3V forward-voltage drop as my green LEDs, which means we can use the same values for our current-limiting resistors.

Of course, you may say that I'm overengineering things, to which I would respond that I'm playing to my strengths because overengineering things is one of the things I do best. Also, I have boxes of LEDs lying around and more LEDs make everything better (a simple rule of thumb, but I'm a simple man). I just added these blue LEDs to my own dual-board combo, which has certainly brightened my day.

Last, but not least, this is a prototype and we're trying to make our lives easier by detecting any potential problems early in the game. We would remove these LEDs if we ever decided to create a production version of our project.

Next time

In our next column, we are going to use the hour and minute values from our RTC to drive our 7-segment display. Think of a time like 12:17 (seventeen minutes past twelve o'clock). This has four digits, but we have only one display. Let's all start thinking about how we are going to use our display to present these values. Until next time, have a good one!

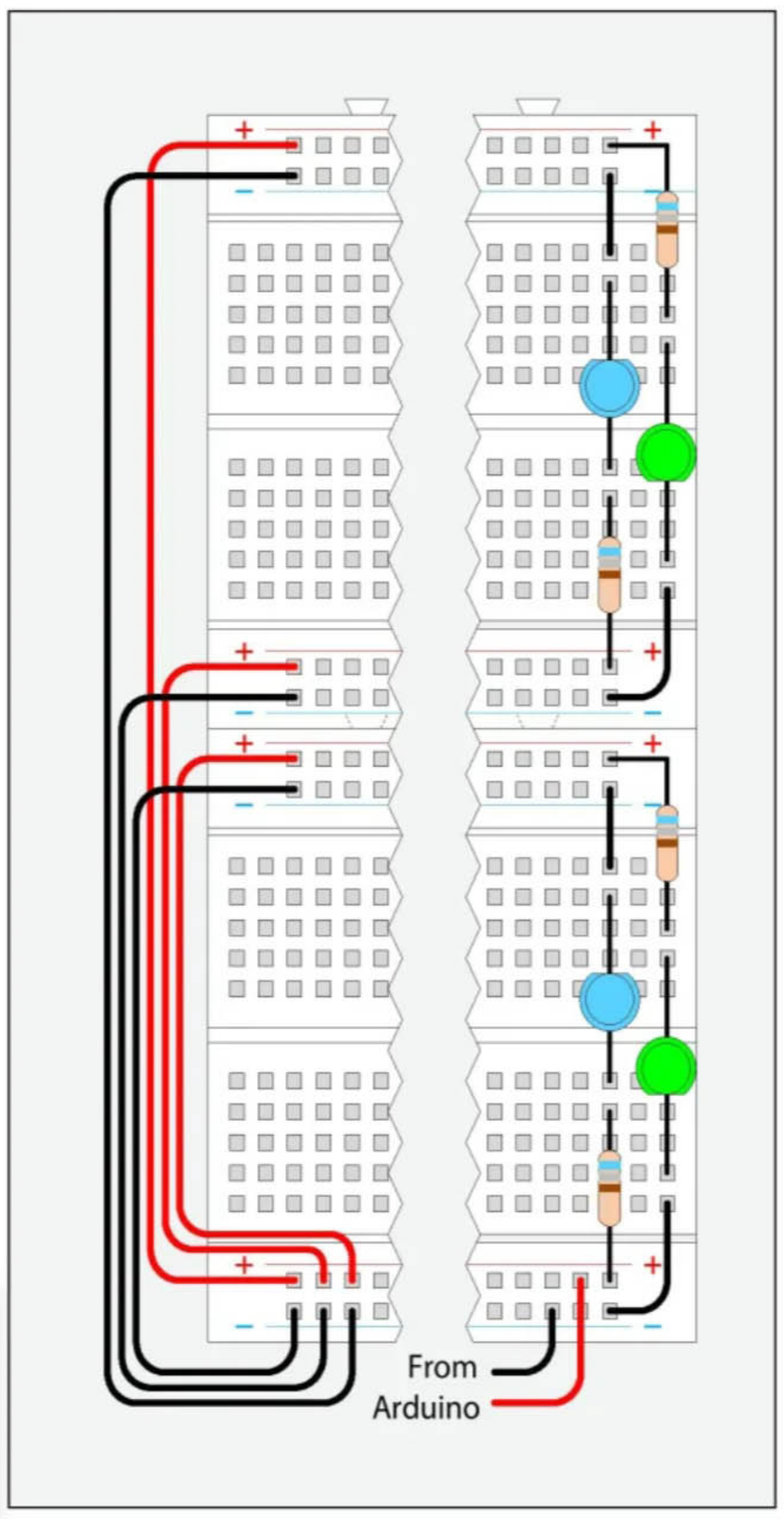


Fig.8. Checking all the power rails.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

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AUDIO OUT

By Jake Rothman

Back to the buffers – Part 2

Last month, we started looking at the design of high-quality discrete buffer circuits. We conclude this month with a complete design.

Fat electrolytics

Referring back to Fig.10 last month, if the coupling capacitor from the sense resistor is too small the distortion rises rapidly at low frequencies. So, when a standard bipolar transistor is used for a current source then the capacitor (C6, Fig.14) must be an electrolytic type. Luckily, this capacitor has almost the supply voltage across it, which ensures full polarisation and gives low distortion.

Wet electrolytics are bulky and unreliable over time and I recommend using tantalum devices for superior reliability. However, high CV product (often listed as µF×rated voltage) tantalum capacitors are expensive. The value can be reduced to a cheap 100nF component if the input impedance of the modulation point on the current load is raised to 470kΩ or over by using a JFET. The trouble here is that high-voltage (>30V) JFETs can also be expensive. The common BF244A is rated at 30V, and the 2SK30 and U1898 will tolerate a 48V power rail. However, the low-voltage rating of standard JFETs is not a problem if ±15V rails are used, as shown in Fig.13. The distortion is a little

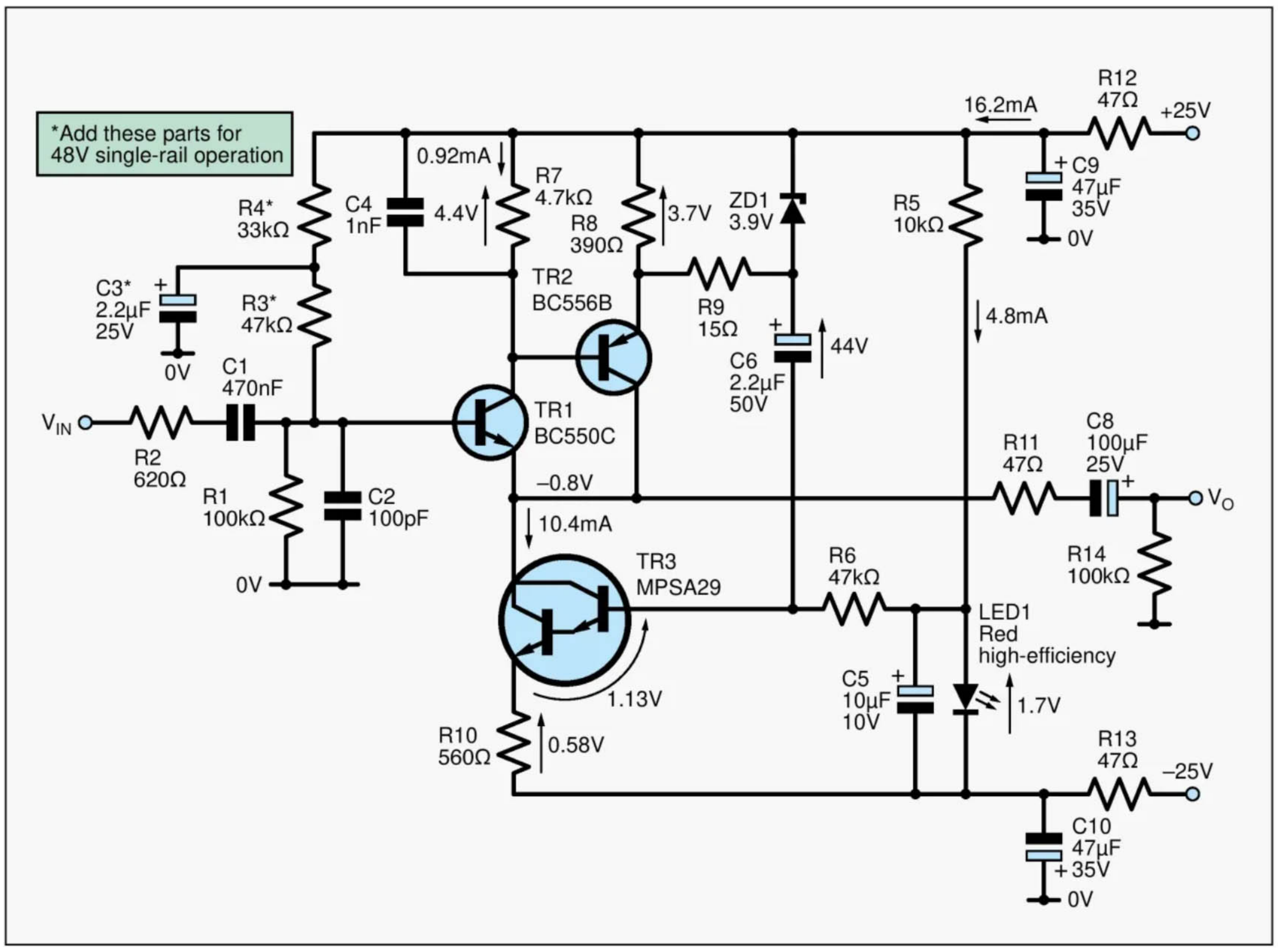
*Add these parts for 48V single-rail operation
R12 47Ω
+25V
16.2mA
0.92mA
R7 4.7kΩ
R8 390Ω
4.4V
3.7V
ZD1 3.9V
R5 10kΩ
+ C9 47µF 35V
0V
R4* 33kΩ
C4 1nF
C3* 2.2µF 25V
0V
R3* 47kΩ
TR2 BC556B
R9 15Ω
C6 2.2µF 50V
44V
4.8mA
C1 470nF
VIN
R2 620Ω
TR1 BC550C
R1 100kΩ
C2 100pF
0V
–0.8V
R11 47Ω
C8 100µF 25V
VO
10.4mA
TR3 MPSA29
R6 47kΩ
R14 100kΩ
LED1 Red high-efficiency
1.13V
C5 10µF 10V
1.7V
R10 560Ω
0.58V
R13 47Ω
–25V
C10 47µF 35V
0V

Fig.14. Reducing the size of C8 by using a Darlington current load. This is the final circuit, with THD of 0.00055%.

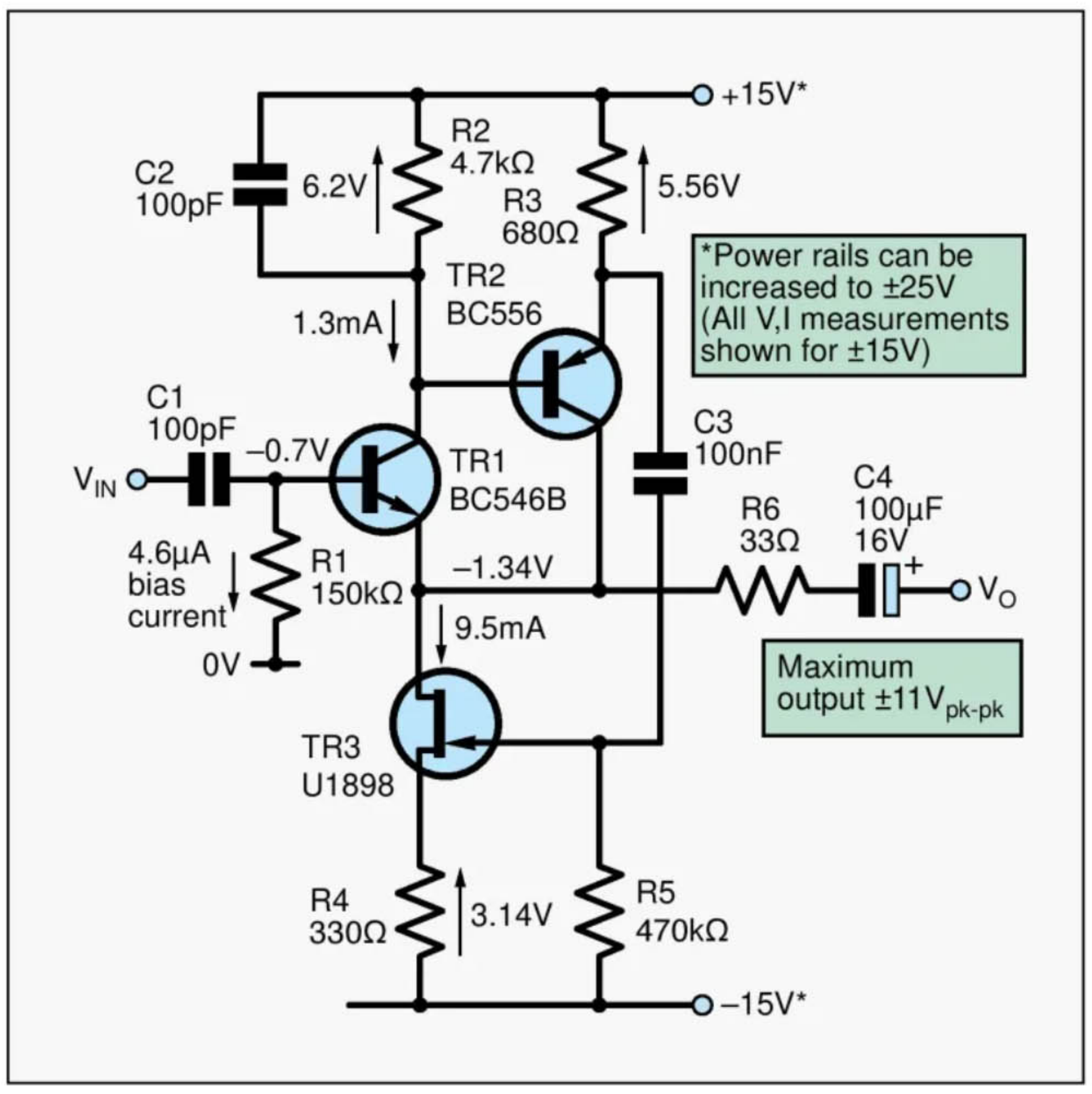
+15V*
C2 100pF
6.2V
R2 4.7kΩ
R3 680Ω
5.56V
1.3mA
TR2 BC556
*Power rails can be increased to ±25V (All V,I measurements shown for ±15V)
C1 100pF
–0.7V
VIN
TR1 BC546B
C3 100nF
R6 33Ω
C4 100µF 16V
VO
4.6µA bias current
R1 150kΩ
–1.34V
0V
9.5mA
Maximum output ±11Vpk-pk
TR3 U1898
R4 330Ω
3.14V
R5 470kΩ
–15V*

Fig.13. CFP-modulated buffer (see *Part 1*, last month). Here, TR3 is a JFET, resulting in 0.003% THD.

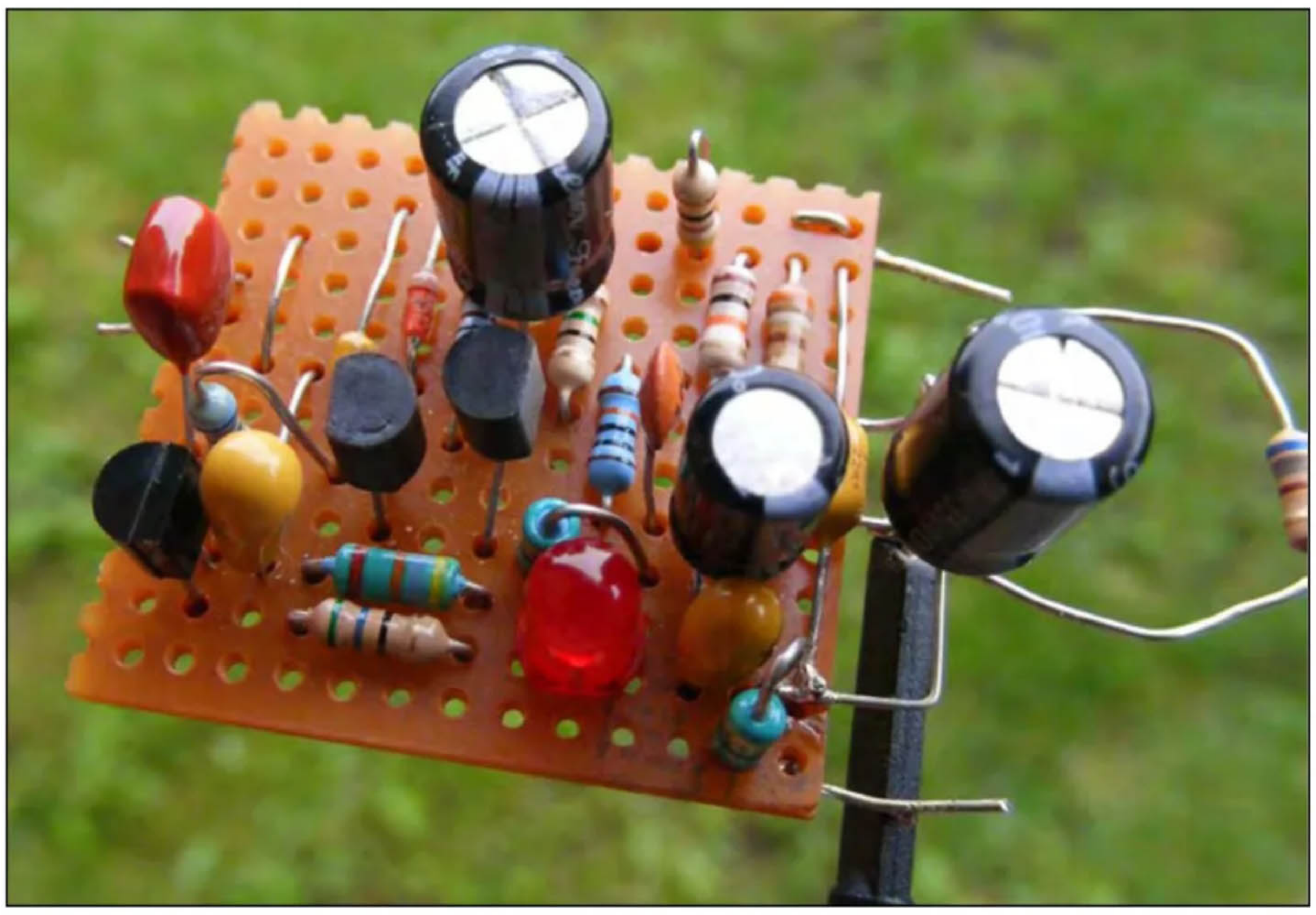

Fig.15. A Veroboard prototype of Fig.14. I should have used a bigger bit of board. Yes, I know there are a lot of fat electrolytics!

higher for a U1819 JFET current sink at 0.0035% because it is more difficult to get the full modulation required to obtain the distortion minima. A sense resistor of 680Ω had to be used to get sufficient drive. The distortion remained at the same level when used at ±25V, whereas it decreased with the bipolar circuits.

An effective solution to the JFET voltage problem is to use a Darlington transistor for the constant-current load. Which leads us to the final Darlington circuit shown in Fig.14. The coupling capacitor (C6) needs to be 2.2µF. The Darlington has a 1.2V V_{be} drop, double that of a normal transistor. This reduces the voltage across the constant-current set resistor (R10) by 0.6V. The residual voltage across R10 is 0.58V and this is used to set the current at 10.3mA.

The Veroboard prototype is shown in Fig.15. To keep the input impedance high, TR1 should be a high H_{fe} device such as a BC550C. I did try a Darlington here, but there was an unexplained distortion rise at 10kHz to 0.005%, so I'm sticking with a regular NPN bipolar transistor.

Components: ±25V/±12V version

The component list for the ±25V version shown in Fig.14 is detailed below. Values for a ±12V version are provided in brackets.

Resistors

R1 100kΩ (150kΩ) 1% metal-film 0.25W
R2 620Ω 1% metal-film 0.25W
R3 omit, but for single-rail fit 33kΩ 1% metal-film 0.25W
R4 omit, but for single-rail fit 47kΩ 5% carbon-film 0.25W
R5 10kΩ 5% carbon-film 0.25W
R6 47kΩ 1% metal-film 0.25W
R7 4.7kΩ 1% metal-film 0.25W
R8 390Ω (120Ω) 1% metal-film 0.25W
R9 15Ω 5% carbon-film 0.25W
R10 56Ω (47Ω)
R11 47Ω 5% carbon-film 0.25W
R12 47Ω 5% carbon-film 0.25W
R13 47Ω link for single rail 5% carbon-film 0.25W
R14 100kΩ 5% carbon-film 0.25W

Capacitors

C1 470nF polyester film 5mm 10%
C2 100pF ceramic 5mm 5%
C3 omit, but for single-rail fit 2.2µF 25V tantalum
C4 470pF, (1nF) ceramic 5mm 5%
C5 10µF 10V tantalum
C6 2.2µF 50V, (35V) tantalum
C7 220nF ceramic 10% 5mm (this is a rail-to-rail decoupling capacitor, not shown on diagrams)
C8 100µF 35V (bi-polar electrolytic is preferable)
C9 47µF 35V electrolytic or polymer
C10 47µF 35V electrolytic or polymer

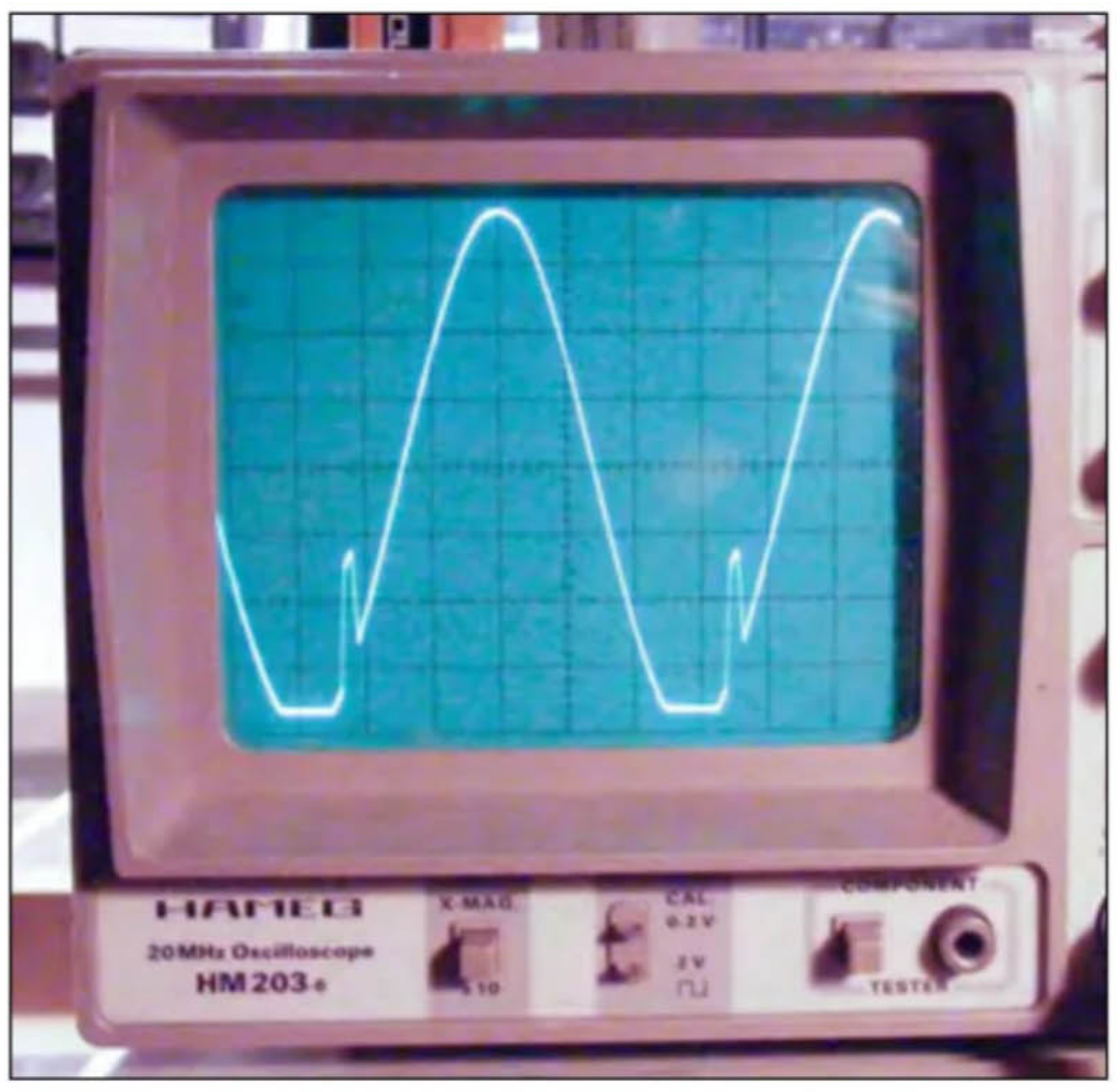

Fig.16. The nasty clip spike sometimes exhibited by over-driven modulated current loads.

Semiconductors

TR1 BC550CB (BC549C) NPN small signal
TR2 BC556B (BC327) PNP small signal
TR3 MPSA29 (MPSA13) NPN small-signal Darlington
LED1 5mm hi-eff red Rapid 55-0155
ZD1 3.9V 400mW BZY88C3V9

Testing to destruction

Most designers don't like to say what's wrong with their circuits, or they never take the circuit out of its comfort zone. In my field I have a whole gang of musicians who 'specialise' in finding imaginative and unexpected ways of destroying electronics. The most recent example was a Tonebender pedal designed to work on a 9V battery, which emitted 'confetti with fireworks' at a wedding gig. It turned out a Hewlett Packard 33V printer power supply had been adapted and connected the wrong way to the pedal (reverse polarity supply voltage). So, I thought it prudent to stress-test the buffer, as explained below.

Crazy clipping

I've come across many amplifier configuration that give lovely low distortion, but then clip horribly. This seems to be the case with the modulated current source loads used in these buffers. A brutal test I do with all audio circuits is to over-drive them and force a hard output clip at 10kHz into full load and then short the output. Sure enough, a problem came up that was invisible at the standard 1kHz test frequency. In this case it was a spike, as shown in Fig.16.

These nasty clipping effects were called 'mode changes' by John Linsley-Hood, an apt description of a stage suddenly conducting or latching in an unforeseen fashion. I think the cause here is the output stage clipping, feeding an excessive distorted modulation signal into the current sink, breaking the modulation control loop. This effect occurs with input excursion magnitudes exceeding –18.5V (eg, –19V). Adding a Zener diode clamp (D1) across the sense resistor (R8) reduced the onset of this effect until –21V. So, if the input voltage stays well below this figure there will be no problem. This situation could be where a buffer *precedes* an amplifier with gain, such as a Baxandall active volume control. If almost full-rail voltage output is required, an op amp or diamond buffer (to be discussed next month) will have to be used.

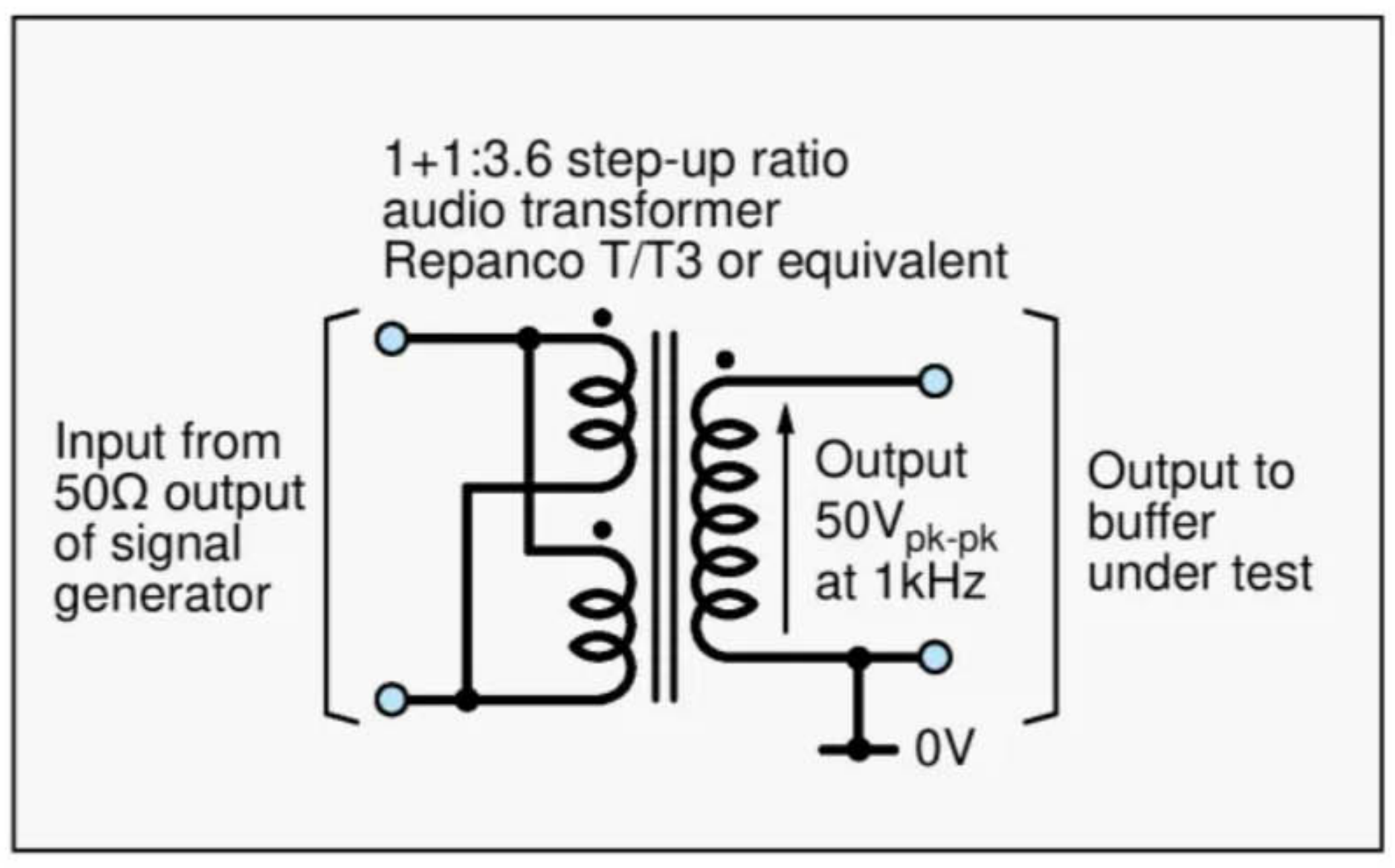

Fig.17. A 1:3.6 ratio audio transformer (type T/T3) can be used to step-up a signal generator output to overdrive buffers with ±25V rails. The transformer will distort at low frequencies and ring on square waves.

Clip testing

Since these discrete buffers are designed to work with high ±25V rails and have unity gain, they have to be fed with a signal voltage as high as this to induce clipping. Very few signal generators can give this level. I suspect this is why the clipping behaviour hasn't been mentioned much in the literature. One way of getting high levels is to use a step-up audio transformer, as

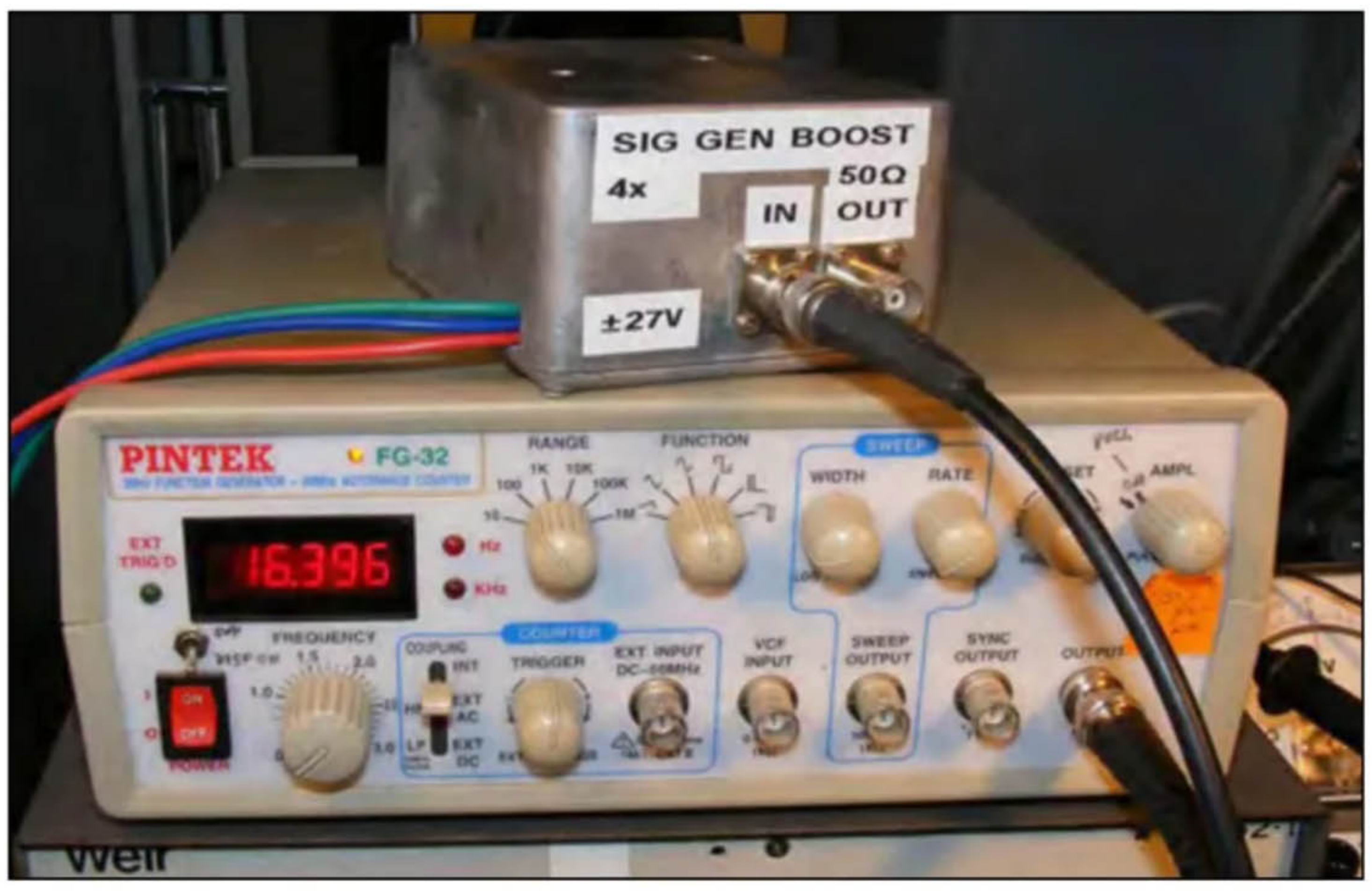

Fig.18. The high-voltage discrete op amp with a gain of 4x makes an excellent signal generator booster, giving a much cleaner waveform than a transformer. However, it does need a high voltage dual-rail power supply.

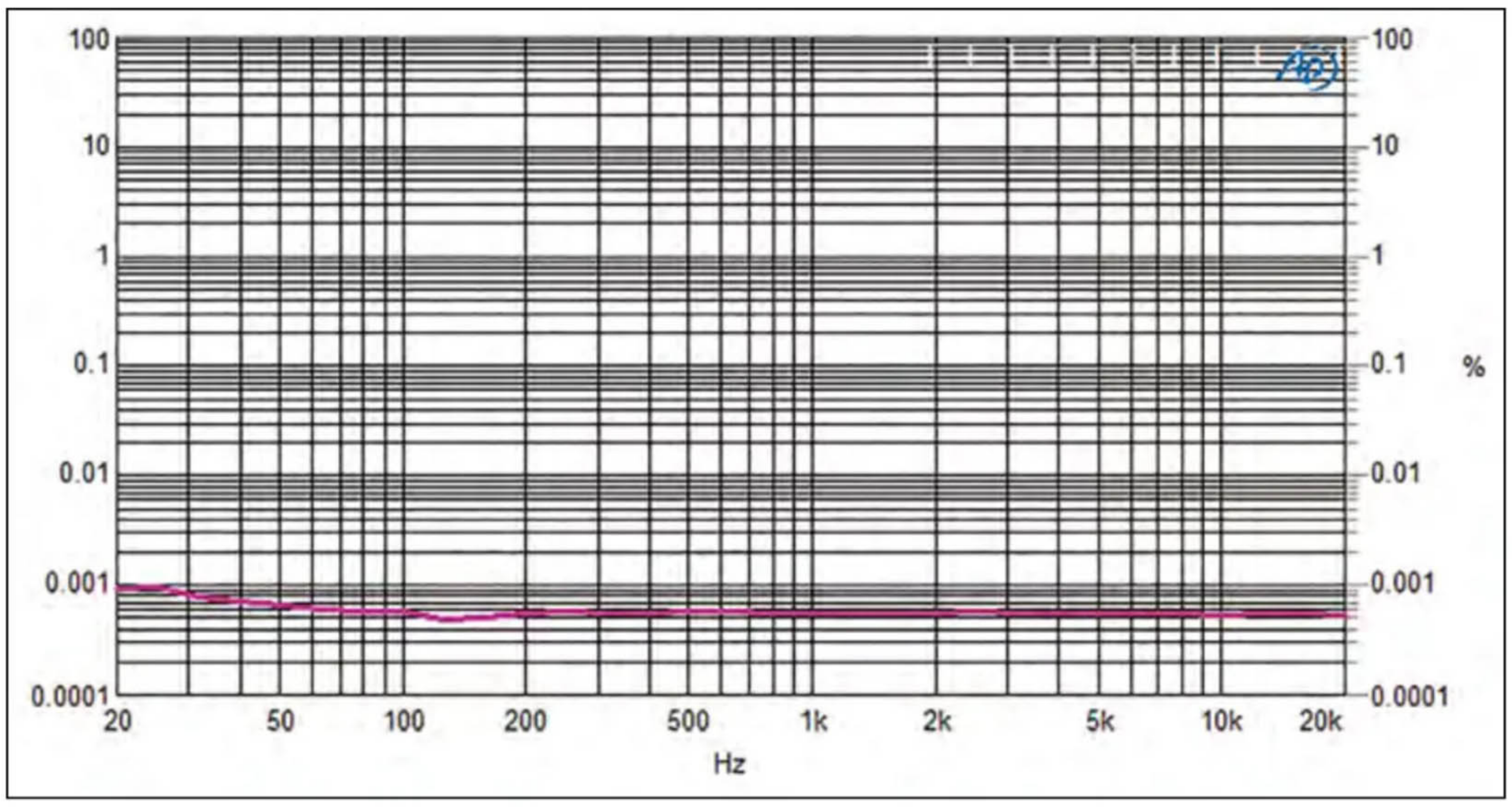

Fig.19. Distortion curve for the final buffer shown in Fig.14 using an MPSA29 for the current sink load, a BC550C for TR1 and ±25V rails gave 0.00055% THD.

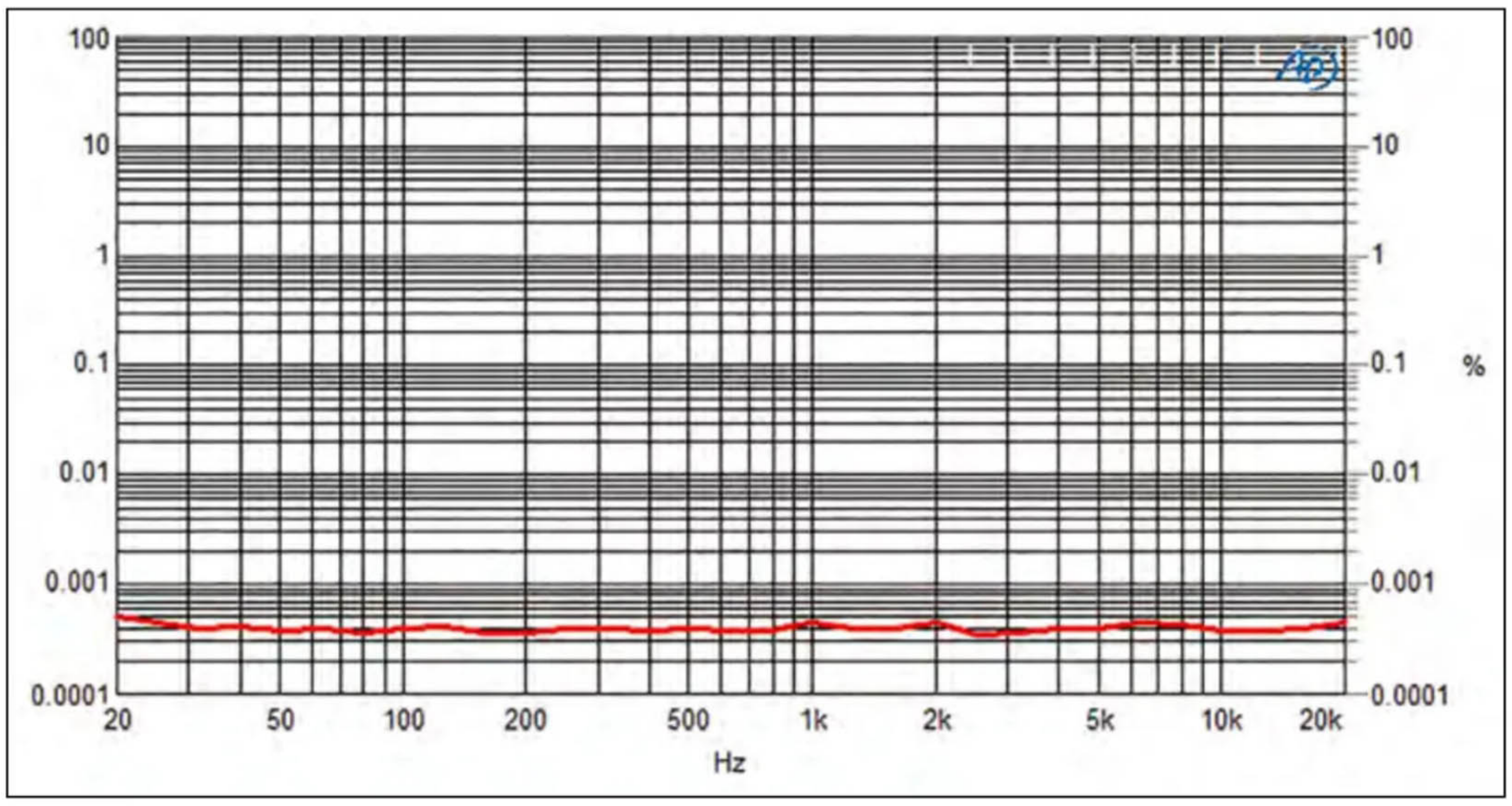

Fig.20. Distortion curve of a dual balanced buffer comprising two of the circuits shown in Fig.14 achieved an excellent 0.00045% THD.

illustrated in Fig.17, although many transformers have distortion problems at these levels. The solution here is to use the discrete op amp discussed in *Audio Out*, October 2023, running at ±27V, as shown in Fig.18 to boost the amplitude of a typical signal generator.

Unforeseen consequences

In electronics, solving one problem usually leads to another. For the discrete buffer in Fig.14, the clamp diode (ZD1) passed a destructive current on the positive rail when the output was shorted. This was fixed by adding a 15Ω resistor (R9). Now when the output is shorted at full clip at 10kHz, there's no smoke, just a current of 80mA flowing in the positive rail and 30mA in the negative. This is survivable short-term with a BC556 (I_c max, pulsed 200mA, continuous 100mA). Note that this current-limiting configuration assumes you have included R11 (47Ω) in series with the buffer output. For a buffer with higher current rating, use a higher-current transistor, such as a 2SA1275Y or ZTX751.

Maximum output

The sense resistor R8 and the current sink consume quite a bit of voltage headroom from the total available power rail voltage of 50V. Also, because the circuit is asymmetrical, clipping occurs on the negative side first. The symmetrical voltage swing available into 600Ω is 42V$_{\text{pk-to-pk}}$. This is a headroom loss of 8V. The more complex discrete op amp (*Audio Out*, October 2023) gives 47V$_{\text{pk-pk}}$. Note that the 47Ω decoupling resistors (R12 and R13) drop an additional 0.8V full load if used.

Specifications for the design in Fig.14

- Maximum current consumption running on ±25V, just before clipping at 10kHz into 600Ω is 18mA on both rails. Under no-signal conditions the current draw is 15mA.
- The buffer's power consumption is 0.9W max.
- Loss of either rail switches the circuit off, and the output goes to the rail
- There is an output offset of –1V, so a DC blocking capacitor is needed on the output.
- The design's frequency response is –1dB at 10Hz and 400kHz (slew limiting sets in at 350kHz at 14V$_{\text{pk-pk}}$).
- Input impedance 90kΩ.
- Output impedance is 34Ω (not including output resistor R11).
- Distortion 0.0006% 0dBm (2.2V$_{\text{pk-pk}}$ into 600Ω) at 1kHz. The distortion curve is shown in Fig.19.

Distortion cancellation

Just out of interest, I arranged two Fig.14 buffer circuits in balanced mode to see if the distortion could be reduced further by push-pull cancellation. This was easy to check since my AP distortion analyser has balanced inputs and outputs. Cancellation is much more

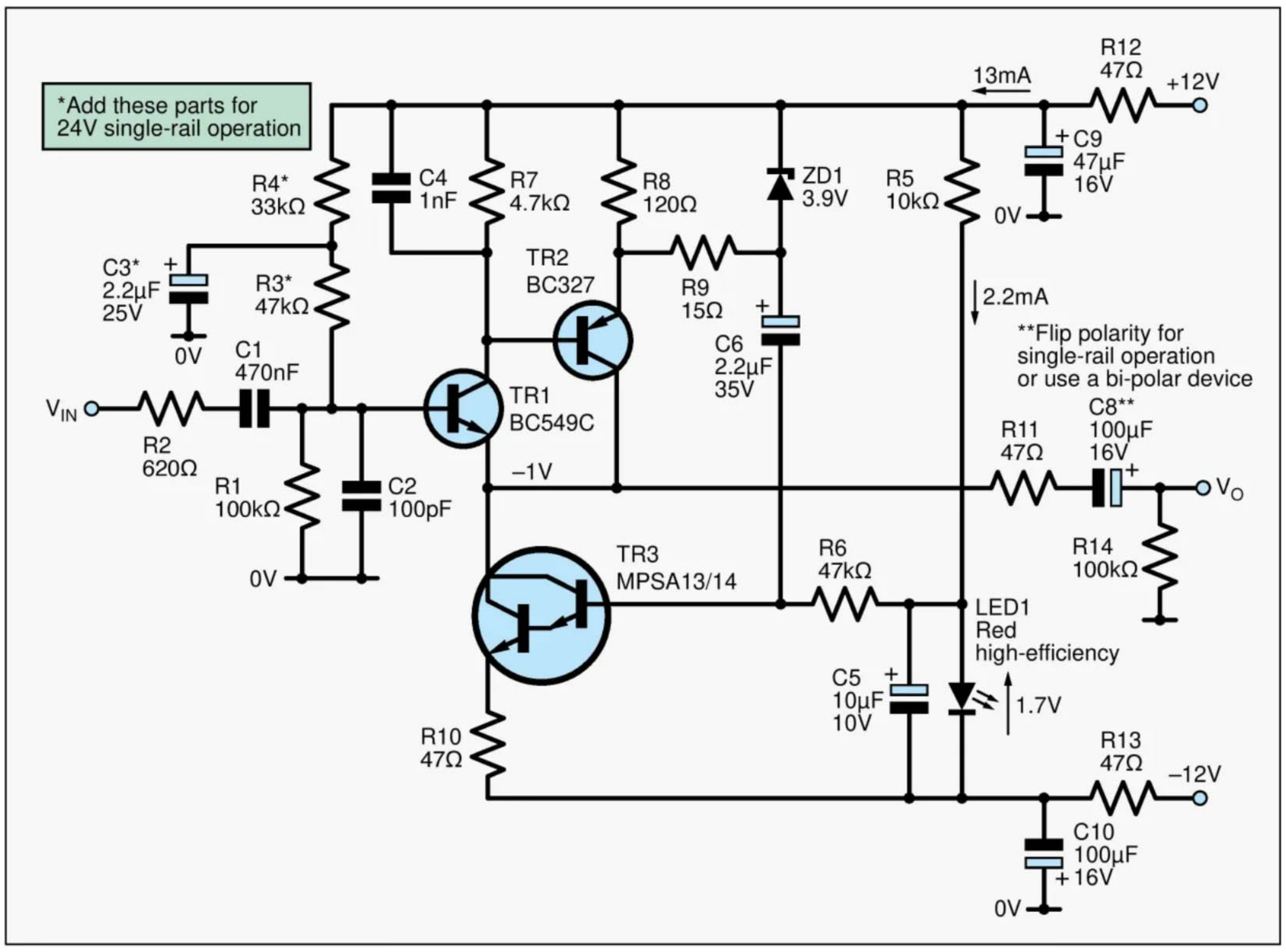
*Add these parts for 24V single-rail operation
R12 47Ω
+12V
13mA
C9 47µF 16V
0V
R4* 33kΩ
C4 1nF
R7 4.7kΩ
R8 120Ω
ZD1 3.9V
R5 10kΩ
C3* 2.2µF 25V
0V
R3* 47kΩ
TR2 BC327
R9 15Ω
C6 2.2µF 35V
2.2mA
**Flip polarity for single-rail operation or use a bi-polar device
C8** 100µF 16V
V_IN
R2 620Ω
C1 470nF
TR1 BC549C
R11 47Ω
V_O
R1 100kΩ
C2 100pF
–1V
0V
TR3 MPSA13/14
R6 47kΩ
R14 100kΩ
LED1 Red high-efficiency
C5 10µF 10V
1.7V
R10 47Ω
R13 47Ω
–12V
C10 100µF 16V
0V

Fig.21. Fig.14 circuit modified to ±12V rails.

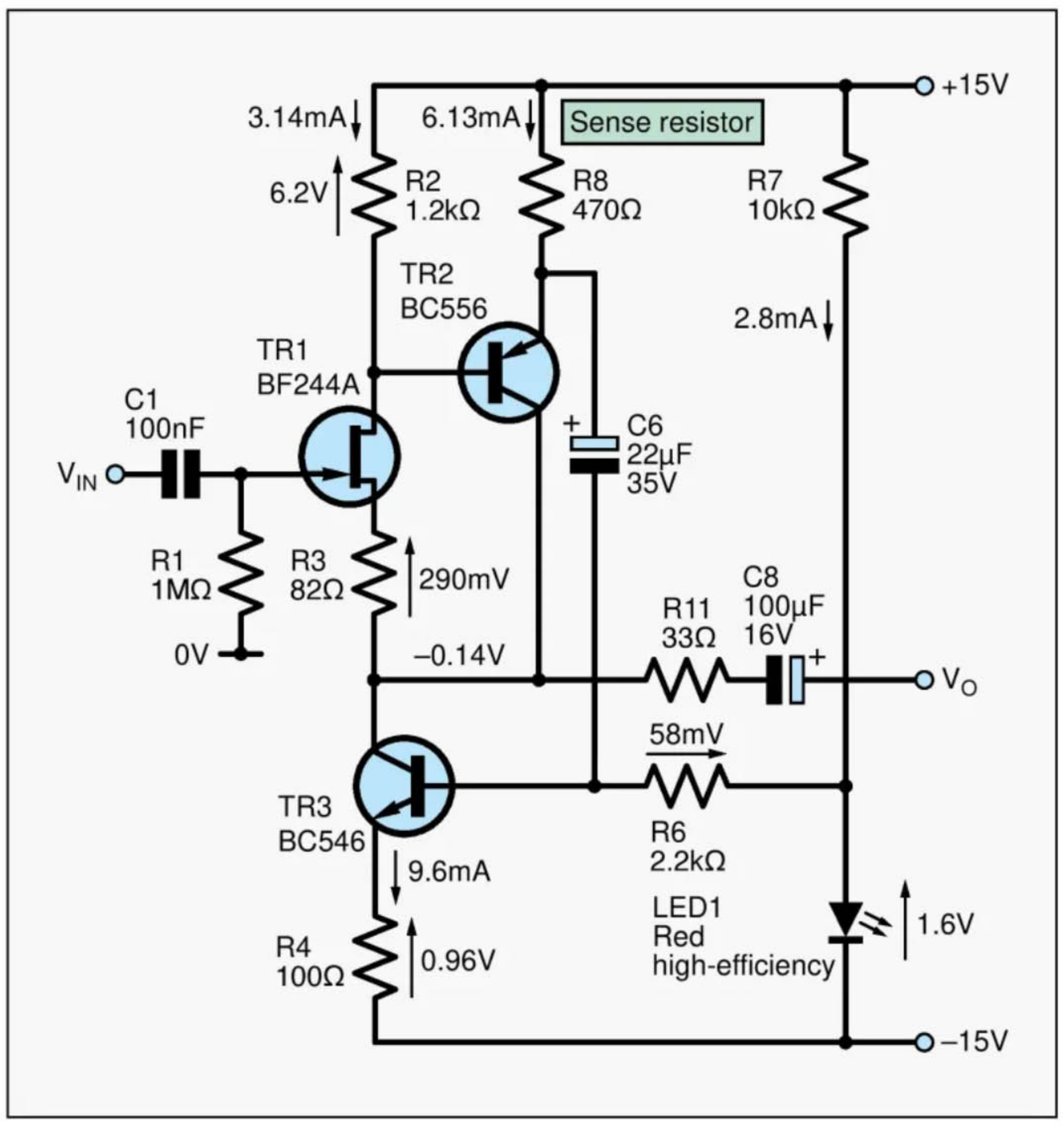

Fig.22. CFP buffer with JFET input. Note this circuit diagram has been simplified by leaving off the decoupling and input filtering components.

effective when the basic distortion is quite high and mainly low even-order harmonics, such as second. This is the case with JFET followers and valve push-pull output stages. It is less effective with low distortion circuits, such as the one given here, but it still made a difference. When used in balanced mode the distortion went down to 0.00045%, as shown in Fig.20.

±12V version

A low-voltage version of the circuit is shown in Fig.21; running off ±12V. It has slightly higher distortion at 0.0025% (compared to Fig.14, ±25V); its maximum output is $20V_{pk\text{-}pk}$.

The voltage rating of the Fig.21 transistors and capacitors can be reduced by half compared to Fig.14. A BC549C is used for TR1 and a BC327 for TR2. TR3 can be the more common MPSA13/4 Darlington, which is rated at 30V. To ensure lowest distortion, R8 is reduced to 120Ω and R10 to 47Ω. The BC327 will drive a lower-impedance load than the BC556. TR2's quiescent current is 11mA. For the whole circuit it's 13mA. If a BF244 JFET is used for TR1, as shown in Fig.22, distortion increases to 0.0035%, but the input impedance is much higher and R1 can be increased to well over 2.2MΩ if needed.

Single-rail operation

To run the buffer off a single rail, insert bias resistors R3/R4. These, along with R1, provide a mid-point bias. In practice, this has to be a bit higher than half rail to ensure symmetrical clipping. C3 decouples the bias to ensure no hum and noise can enter the input via the bias network. The negative rail and ground rail have to be linked. This is done by shorting both C10 and R13 with links. In single-rail operation, the ±12V version is run on +24V and the ±25V version can be run at 48V or 50V. Remember that C8 has to be reversed. The bias network components R3, R4 and C3 can also be used for bias current compensation to null the output offset on the dual-rail units. A total R3+R4 resistance of around 820kΩ should do it.

Buffer stop

Is that the end of the design? Well not quite, we'll be doing more buffers, such as the diamond, next month. I also thought it would be a good idea to combine the balanced discrete op amp with a couple of buffers to make an ultra-low noise and low-distortion balanced input amplifier, which will also be discussed next month.

Teach-In 8 CD-ROM
Exploring the Arduino

This CD-ROM version of the exciting and popular *Teach-In 8* series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. *Teach-In 8* provides a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle wirelessly or via the Internet. *Teach-In 8* is based around a series of practical projects with plenty of information for customisation. The projects can be combined together in many different ways in order to build more complex systems that can be used to solve a wide variety of home automation and environmental monitoring problems. The series includes topics such as RF technology, wireless networking and remote web access.

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INTRODUCING THE ARDUINO

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SOFTWARE
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NPN transistors

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Diodes

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Si semiconductors

Diodes

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BFW16A, 2SC3071, 2SC3068, 2SA1016K, 2SC2362K, 2SA970BL	**£1.50**
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ZTX651	**£0.30**
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RF transistors (suitable for Theremin)

BF199	**£0.50**

Audio power MOSFETs

Exicon 10N20, 10P20	**£6.50**
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Hitachi 2SJ56, 2SK176	**£8.50**

JFETs

BFW11, BFW10, TIS73L, J177, J113, U1994, U1898, 2SJ176, J201	**£1.00**
J175, J176, J112, J111, 2N3820, 2N5467, BF244, 2N5460, J230	**£0.60**

Small power output/driver transistors

2SB649A, D669A, 2SA1208, 2SC2910, MJE253G, MJE243G, 2SA1725, 2SC4511	**£1.20**
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TAA435 (Mullard power amp driver)	**£1.20**

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That/dbx 2180 VCA/VCF	**£6.00**
CA3080 VCA/VCF (vocoder)	**£2.80**
CA3280 VCA/VCF	**£4.00**
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PE Mini-Monitor

Volt PE165 6.5-inch woofer (each)	**£85**
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Capacitors

Note '10/63' denotes '10µF 63V'.

Polyester

3.3/100, 4.7/250, 4.7/63	**£1.00**
5.6/63, 8.2/63, 10/63	**£2.00**
Mullard 'Mustard' C296 0.22/400	**£2.00**

Polycarbonate

Axial 2.2/63 1%, 4.7/160, 6.8/63	**£1.00**

Radial

6.8/160V, 10/63	**£2.00**
Reclaimed 22/63	**£2.00**

Polystyrene

Philips 1% 4.7nF/160, 6.2nF/500, 12nF/63, 22nF/63, 110nF/63, 24nF, 2nF	**£1.00**
RIFA 1% 100nF/100, Suflex 90.9nF 0.5%	**£2.00**
Suflex 2.5% 10nF/63 (rad. or ax.)	**£0.50**

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Siemens cellulose acetate MKL 2.2/25	**£0.80**

Electrolytic – Mullard blue 017 series

10/25, 22/25, 100/10	**£0.50**
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22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	**£2.00**
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	**£1.25**
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Kemet axial 6.8/10	**£0.30**
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Vishay plastic-film 10-250pF	**£2.00**
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LT44, LT722 driver, LT700, LT723 500Ω output	**£2.50**
LT30 500mW output	**£3.50**
5:1 interstage	**£1.50**

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CH2 5mH RFC	**£2.00**

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Vigortronix 600Ω VTX-101-3001	**£10**
Vigortronix 600Ω VTX-101-3002	**£15**
Gardners 150Ω	**£10**
Reclaimed BBC LL74/MPC nickel core 600Ω	**£12**

Reclaimed mic input transformer	**£15**

Inductors

82µH, 4.7mH, 100µH, 270µH, 10µH, 14µH (low Z)	**£0.50**
7-inch ferrite rod with MW and LW windings	**£3.00**

Special resistors

Bourns wire-wound trimmer 5kΩ 3059 JM panel-mount	**£2.00**
Thermistor RA53, R13	**£4.00**
A13	**£2.00**
Thermistor CZ1, CZ6	**£1.50**
Holco H2 2.2MΩ 1W, 1%	**£1.00**
Welwyn 1GΩ 2W	**£1.00**
5k Bourns 3321H cermet trimmer	**£0.50**

Potentiometers

Bourns 81

25kΩ lin cermet	**£2.00**
25kΩ lin, 5kΩ lin conductive plastic	**£3.00**

Bourns 91

10k dual-gang lin or log	**£10.00**

Plessey moulded-track

5kΩ log with switch	**£3.00**
50kΩ A/log	**£3.00**
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10kΩ lin 1 million cycles	**£5.00**
Blore Edwards AB 45 dual 5kΩ A/log with switch	**£3.50**
Alps RK9 dual-gang 5kΩ RD law	**£4.00**
Alps 50k log tapped motorised stereo	**£5.00**
BI P260 500kΩ log conductive plastic 1 million cycles	**£2.00**
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	**£5.00**
Mil Spec hermetic 10Ω	**£8.00**

Miscellaneous

Theremin Clearance Sale!

Elysian Theremin MIDI box	**£300**

PCBs

Pocket Theremin (*EPE*, 1996)	**£2.00**
Elysian Theremin (*EPE*, 1996)	**£6**
Synth VCF, VCO (*EPE*, 2017)	**£3.00**
48V PSU (*EPE*, 2019)	**£3.00**
SMT dual transistor adapter	**£0.40**

Contact
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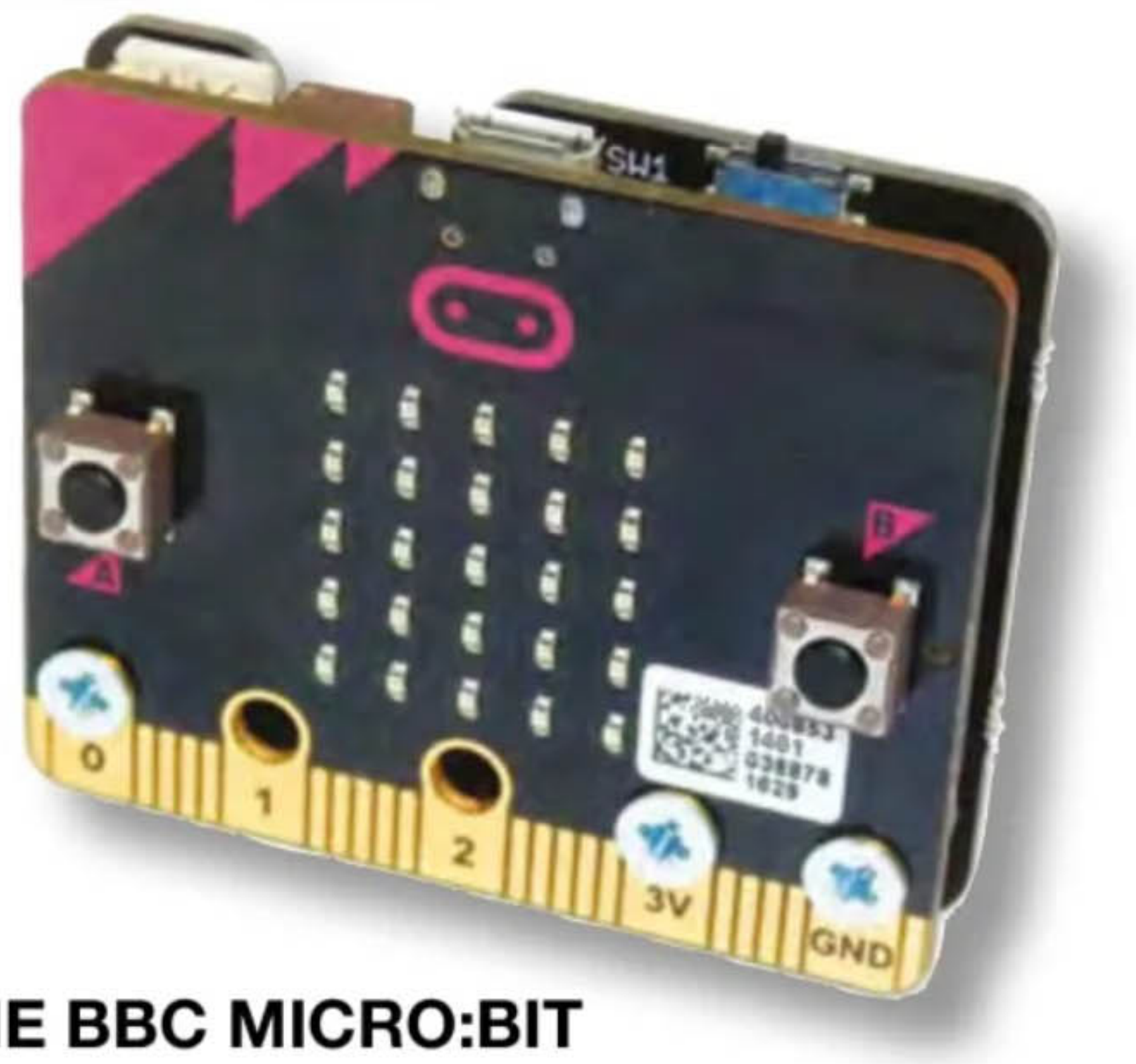
Teach-In 2017

Introducing the BBC micro:bit



IN FULL COLOUR
For Beginners of Any Age
Python Coding on the BBC micro:bit
Jim Gatenby

PYTHON CODING ON THE BBC MICRO:BIT

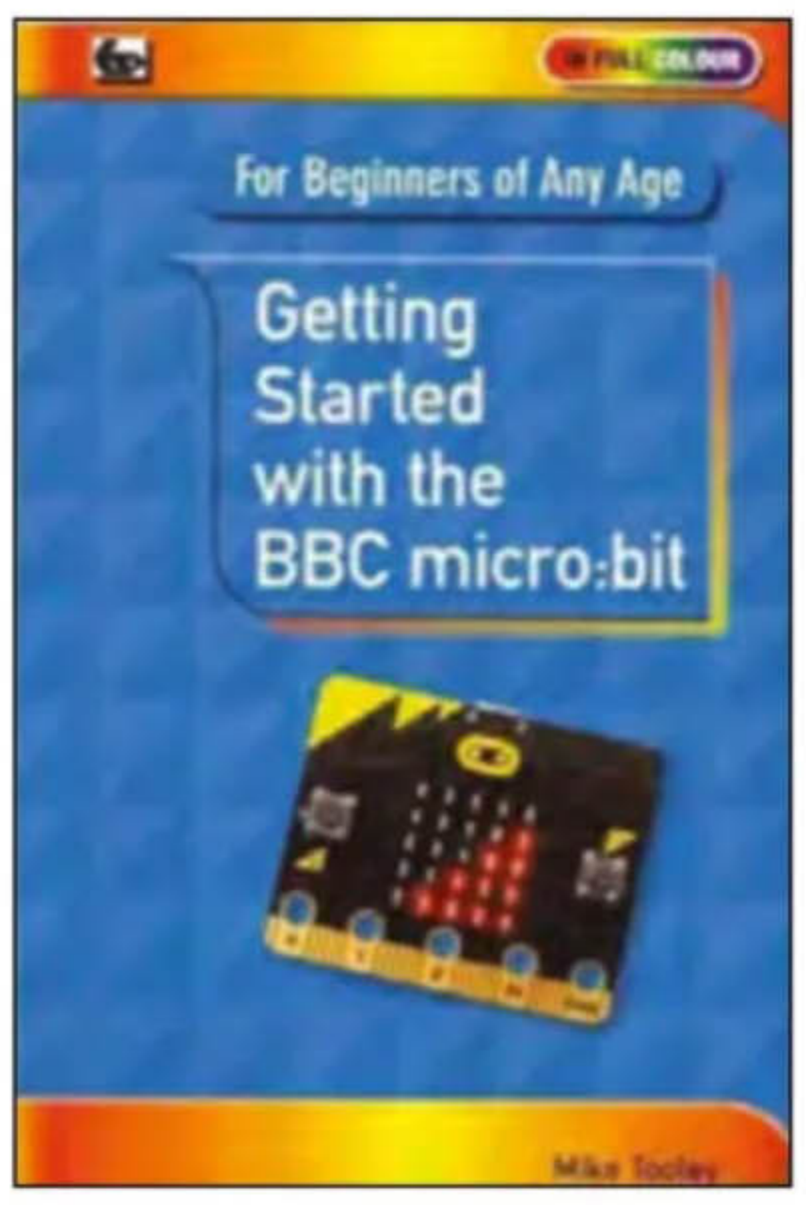
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** **£7.99**



GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages **Order code BBC MBIT** **£7.99**

THEORY AND REFERENCE

PRACTICAL ELECTRONICS HANDBOOK – 6th Ed
Ian Sinclair
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Mike Tooley
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C.R. Robertson
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A BEGINNER'S GUIDE TO TTL DIGITAL ICs
Robert Penfold
142 pages **OUT OF PRINT BP332** **£5.45**

UNDERSTANDING ELECTRONIC CONTROL SYSTEMS
Owen Bishop
228 pages **Order code NE35** **£36.99**

The books listed here have been selected by the *Practical Electronics* editorial staff as being of special interest to everyone involved in electronics and computing. They are supplied by mail order direct to your door.

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MICROPROCESSORS

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Martin Bates
298 pages **Order code NE48** **£34.99**

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Lucio Di Jasio (Application Segments Manager, Microchip, USA)
496 pages + CD-ROM **Order code NE45** **£38.00**

INTRODUCTION TO MICROPROCESSORS AND MICROCONTROLLERS – 2nd Ed
John Crisp
222 pages **Order code NE31** **£29.99**

THE PIC MICROCONTROLLER YOUR PERSONAL INTRODUCTORY COURSE – 3rd Ed
John Morton
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Mike James
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Practical Electronics PCB SERVICE

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FEBRUARY 2024		
Active Mains Soft Starter	10110221	10.95
JANUARY 2024		
Q Meter	CSE220701	8.95
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AUGUST 2023		
110dB RF Attenuator	CSE211003	9.95
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Wide-Range OhmMeter	04109221	12.95
JULY 2023		
Multimeter Checker/Calibrator	04107221	10.95
MIDI Spectral Sound Synthesiser (full kit – see p.25)	N/A	N/A
JUNE 2023		
Arduino Programmable Load	04105221	8.95
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MAY 2023		
Precision AM-FM DDS Signal Generator	CSE211002	14.95
Improved SMD Test Tweezers programmed PIC	0410621PIC	12.95
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AO 2x-dual-to-quad SMD (pack of five)	AO2-MAY23	6.95
AO 2x-single-to-dual through-hole (pack of five)	AO3-MAY23	6.95
AO 2x-single-to-dual SMD (pack of five)	AO4-MAY23	6.95
APRIL 2023		
500W Amplifier Module	see p.22, April 2023	
Clipping Indicator (per channel)	01112211	7.95
CD Welder Power Supply (one needed)	29103221	9.95
CD Welder Controller (one needed)	29103222	9.95
CD Welder Energy Storage module (several needed)	29103223	7.95
AO Universal Dual Op Amp Board	AO1-APR23	9.95
AO Stereo RIAA precision passives kit for dual op amp	AO2-APR23	8.95

PROJECT	CODE	PRICE
MARCH 2023		
Pico BackPack	07101221	9.95
Semaphore Signal (controller)	09103221	7.95
Semaphore Signal (blade)	09103222	5.95
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Tesla Coil driver board	26102221	9.95
Tesla Coil potentiometer board	26102222	5.95
Cooling Fan Controller & Loudspeaker Protector	01102221	8.95
Remote Gate Controller	11009121	12.95
JANUARY 2023		
Classic LED Metronome – 8-LED	23111211	7.95
Classic LED Metronome – 10-LED	23111212	8.95
Multi-Channel Speaker Protector – 6 channel	01101221	9.95
Multi-Channel Speaker Protector – 4 channel	01101222	7.95
Remote Control Range Extender – IR-to-UHF	15109212	5.95
Remote Control Range Extender – UHF-to-IR	15109211	7.95
AO Universal Single Op Amp Board	AO1-JAN23	7.95
DECEMBER 2022		
Hummingbird Amplifier	01111211	9.95
SMD Trainer PCB	29106211A	8.95
SMD Trainer PCB + parts	29106211B	13.95
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USB Cable tester – main PCB	04108211	12.95
USB Cable tester – front panel	04108212	5.95
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AO transfmr PCB – dual-outline VTX102-3001/101-3002	VTX-Dual	6.95
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20A DC Motor Speed Controller	11006211	9.95
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Multi-purpose Battery Manager – I/O Expander module	11104212	5.95
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Simple MIDI Music Keyboard (for 8 switches)	23101213	6.95
Nano Pong	08105212	7.95
JULY 2022		
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Level Crossing Controller	09108211	6.95
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PIC Programming Helper for 8-pin PICs only	24106211	7.95
PIC Programming Helper for 8, 14 or 20-pin PICs	24106212	10.95
Advanced GPS Computer	05102211	9.95
MAY 2022		
Bus board PCB for Analogue Vocoder	AO1-MAY22	10.95
Complete set of 14 PCBs for Analogue Vocoder	AO2-MAY22	97.95
Programmed EEPROM for Digital FX Unit	FX1-MAY22	10.95
Programmed PIC for Digital FX Unit using potentiometer	FX2-MAY22	8.95

PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

PROJECT	CODE	PRICE
APRIL 2022		
64-key MIDI Matrix shield	23101211	8.95
64-key MIDI Matrix switch board	23101212	11.95
High-current Battery Balancer	14102211	10.95
Digital FX Unit – using potentiometer	01102211	9.95
Digital FX Unit – using BCD switch	01102212	9.95
Universal Audio PSU	AO1-APR22	11.95
MARCH 2022		
Mini Isolated Serial Link	24102211	£5.95
Busy Loo Indicator	16112201	£5.95
Analogue Vocoder – Band-pass filter board	AO1-MAR22	9.95
Analogue Vocoder – HP/LP filter board	AO2-MAR22	9.95
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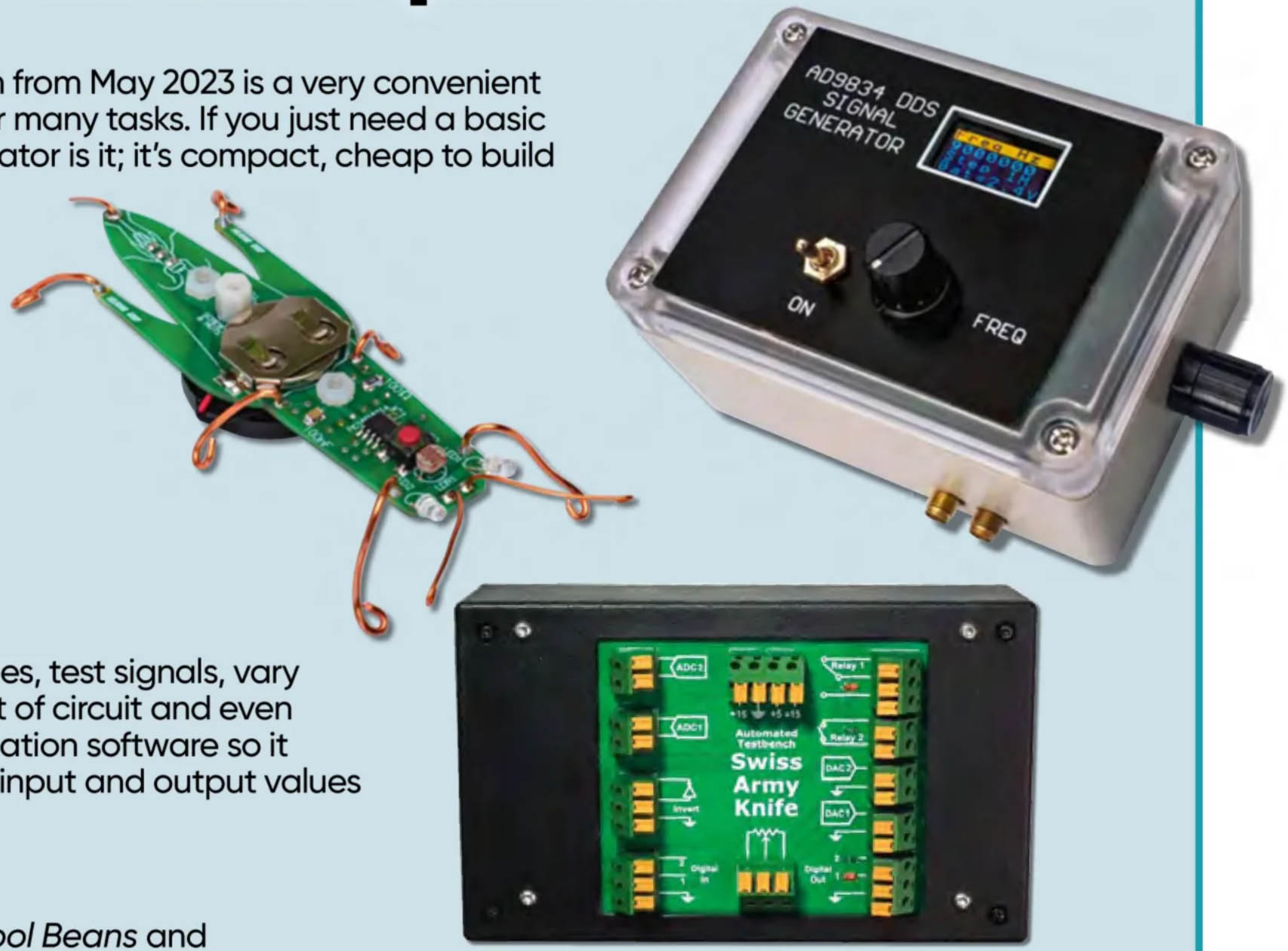
Next Month – in the April issue



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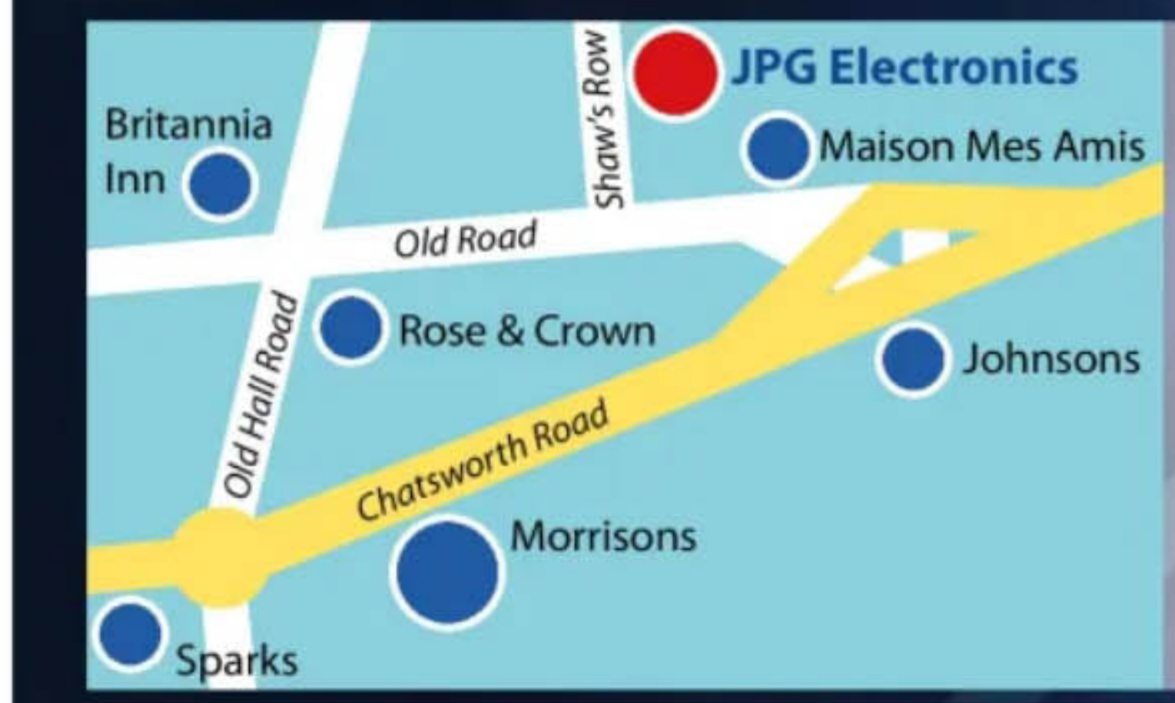

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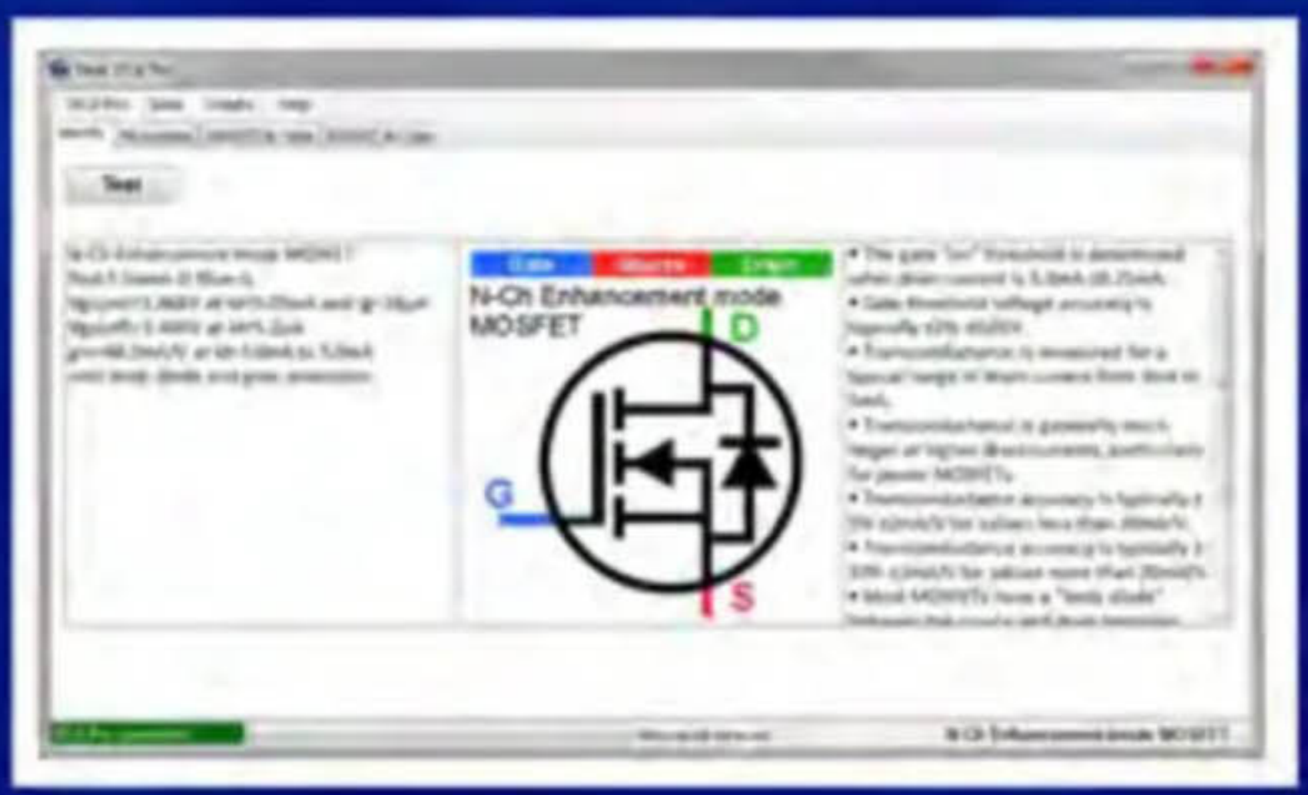
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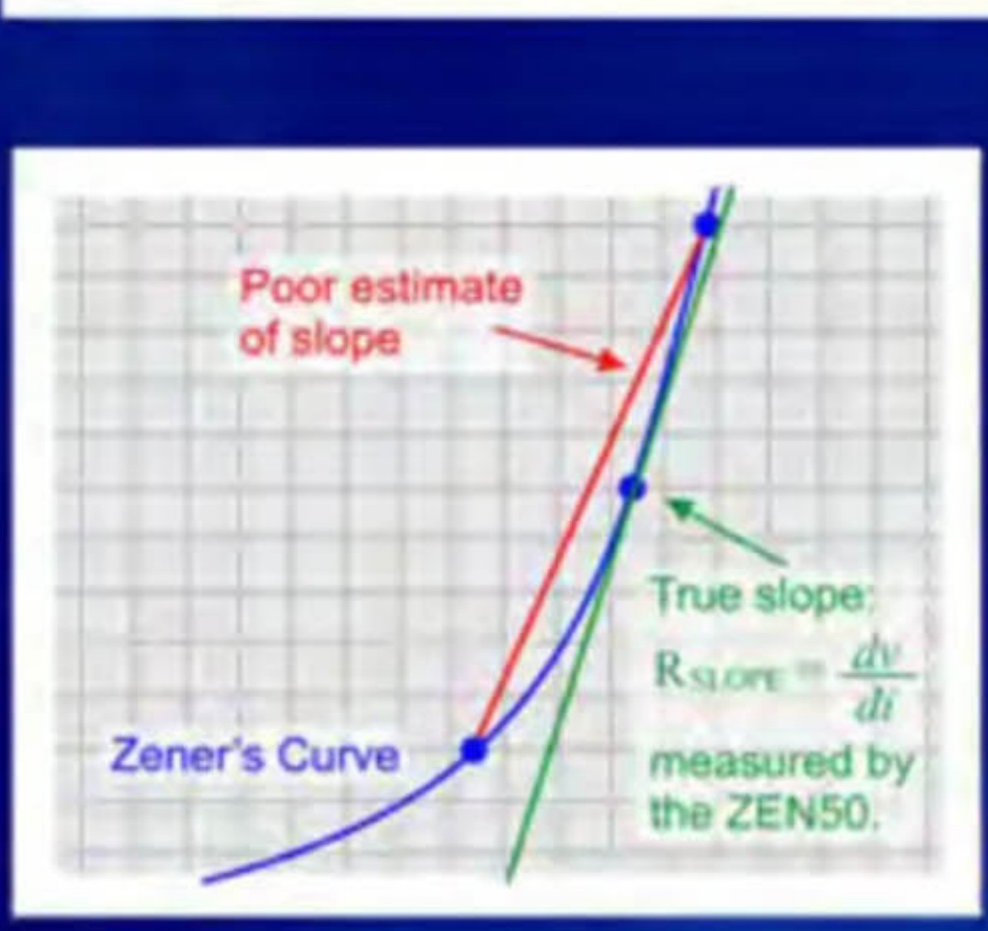

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